NEMATIC LIQUID CRYSTAL DISPLAY DEVICE WITH MULTI-DOMAIN
PIXELS

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION:

The present invention relates to a liquid crystal
5   display device as a computer monitor and a liquid crystal
display device for displaying video images and, more
particularly, to a liquid crystal display device having
desirable viewing angle characteristics.

2. DESCRIPTION OF THE RELATED ART:

10   Various display modes have been proposed for
improving the viewing angle of a liquid crystal display
device. Typical examples of such display modes include:
① IPS (In-Plane Switching) mode which uses a transverse
15   electric field to move the liquid crystal molecules in
parallel with the substrate surface; ② a liquid crystal
display device in which the liquid crystal molecules are
oriented substantially vertically to the substrate
surface in the absence of an applied voltage, and the
20   liquid crystal molecules in different regions are inclined
in respectively different directions in the presence of
an applied voltage (Japanese Laid-Open Publication
No. 7-28068); ③ a liquid crystal display device in which
the liquid crystal molecules are oriented substantially

horizontally to the substrate surface in the absence of an applied voltage, and the liquid crystal molecules in different regions rise in respectively different directions in the presence of an applied voltage, thereby

5   improving the viewing angle of the device (Japanese Laid-Open Publication No. 10-3081); and ④ a liquid crystal display device of a normally black mode producing a black display in the absence of an applied voltage, in which an optical compensator is used to improve the viewing

10   angle of the device (Japanese Laid-Open Publication No. 5-289097).

In the IPS mode ①, however, it is necessary to provide a plurality of opaque electrodes in a pixel,

15   thereby reducing the aperture ratio and thus the transmissivity (brightness) of the device. The liquid crystal display device ② disclosed in Japanese Laid-Open Publication No. 7-28068 employs a liquid crystal material having a negative dielectric anisotropy (n-type liquid

20   crystal material) and a substrate which has been subjected to a vertical alignment treatment. In such a case, the liquid crystal injection process takes a period of time twice as long as that for a device which employs a p-type liquid crystal material having a positive dielectric

anisotropy and a substrate which has been subjected to a horizontal alignment process, thereby reducing the production efficiency. The liquid crystal display device ③ disclosed in Japanese Laid-Open Publication No. 10-

5 3081 employs transparent electrodes provided respectively on the upper and lower substrates to drive the liquid crystal molecules, thereby avoiding the reduction in transmissivity as in the IPS mode. Moreover, The liquid crystal display device ③ employs a liquid crystal

10 material having a positive dielectric anisotropy and a substrate which has been subjected to a horizontal alignment treatment, thereby also avoiding the reduction in production efficiency as in the device ②. However, the device ③ has viewing angle characteristics that are

15 inferior to those of the device ②. Particularly, the device ③ has asymmetric gray scale characteristics in the vertical direction along the display plane.

Referring to Figure 55, the liquid crystal dis-

20 play device ④ disclosed in Japanese Laid-Open Publication No. 5-289097 includes a liquid crystal panel 4, a birefringence anisotropy compensation panel 3 provided optically continuously on the liquid crystal panel 4 for optically compensating the birefringence anisotropy of

the liquid crystal panel **4** along the plane thereof, a viewing angle dependency compensation panel **2** provided on the birefringence anisotropy compensation panel **3**, and a pair of polarizers **1** and **5** interposing the panels **2**, **3** and **4** therebetween, so that the absorption axes (1.1) and (5.1) are perpendicular to each other. The birefringence anisotropy compensation panel **3** is arranged so that the optical axis (3.1) or (3.2) (or rubbing direction) thereof is parallel to the substrate surface of the liquid crystal panel **4** and perpendicular to the optical axis (4.1) or (4.2) (or rubbing direction) of the liquid crystal panel **4**. The viewing angle dependency compensation panel **2** is arranged so that the optical axis (2.1) (or rubbing direction) thereof is perpendicular to the substrate surface of the liquid crystal panel **4**. The device ④ provides a certain level of improvement in the viewing angle characteristics thereof by employing the viewing angle dependency compensation panel **2**. However, the contrast of the device ④ is reduced as the viewing angle is inclined or shifted from a direction normal to the display plane. Thus, the viewing angle characteristics of the device ④ are not sufficiently desirable. Moreover, it is difficult to stably obtain a uniform orientation and transmissivity across the display

plane of the liquid crystal panel **4** of the device ④ in the presence of an applied voltage.

SUMMARY OF THE INVENTION

According to one aspect of this invention, a liquid crystal display device includes: a first transparent substrate and a second transparent substrate; a liquid crystal layer interposed between the first and second substrates, the layer being made of a nematic liquid crystal material having a positive dielectric anisotropy; a first electrode and a second electrode provided on the first and second substrates, respectively, for applying an electric field substantially vertical to the first and second substrates across the liquid crystal layer; and a first polarizing plate and a second polarizing plate each provided on an outer side of respective one of the first and second substrates, the first and second polarizing plates being arranged in a crossed Nicols arrangement. The liquid crystal layer in each pixel region includes at least a first domain and a second domain in which liquid crystal molecules are oriented in different orientations. A first phase difference compensator having a positive refractive index anisotropy

is provided between the first polarizing plate and the first substrate, and a second phase difference compensator having a positive refractive index anisotropy is provided between the second polarizing plate and the second substrate, so that phase-delay axes of the first and second phase difference compensators are parallel to a substrate surface and to each other, and substantially perpendicular to a phase-delay axis of the liquid crystal layer in the absence of an applied voltage. At least one third phase difference compensator is provided between the first polarizing plate and the first phase difference compensator or between the second polarizing plate and the second phase difference compensator. A refractive index ellipse of the third phase difference compensator has three main axes a, b and c, and refractive indexes of na, nb and nc along the main axes a, b and c, respectively, wherein a relationship nc>na>nb holds, with the main axis a and the main axis b lying in a plane parallel to the substrate surface, the main axis c being parallel to a direction normal to the substrate surface, and the main axis a being perpendicular to a polarization axis of one of the polarizing plates which is adjacent to the phase difference compensator. The first, second and third phase difference compensators compensate for a refractive

index anisotropy of the liquid crystal molecules of the liquid crystal layer which are in a substantially horizontal orientation with respect to the substrate surface in the absence of an applied voltage.

In one embodiment of the invention, where a retardation value of the liquid crystal layer is $d_{lc} \cdot \Delta n$, an in-plane retardation of the third phase difference compensator is $d \cdot (na-nb)$, and a retardation along a thickness direction thereof is $d \cdot (na-nc)$; parameters RL and NZ are defined as follows

$$RL = d \cdot (na-nc)/(d_{lc} \cdot \Delta n), \text{ and}$$

$$NZ = (na-nc)/(na-nb);$$

two of the third phase difference compensators are provided respectively between the first polarizing plate and the first phase difference compensator, and between the second polarizing plate and the second phase difference compensator, with a sum of RL values of the two third phase difference compensators being defined as RLsum; then,

$$0 \leq |RLsum| \leq 2; \text{ and}$$

each of the third phase difference compensators satisfies $\log(|NZ|) \geq 2.0 \cdot |RL| - 1.2$, where $RL < 0$ and $NZ < 0$.

In one embodiment of the invention, the RL value
and the NZ value of one of the two third phase difference
compensators are equal to the RL value and the NZ value,
respectively, of the other one of the two third phase
5   difference compensators.

According to another aspect of this invention, a
liquid crystal display device includes: a first substrate
and a second substrate at least one of which is
10   transparent; a liquid crystal layer interposed between
the first and second substrates, the layer being made of
a nematic liquid crystal material having a positive
dielectric anisotropy; a first electrode and a second
electrode provided on the first and second substrates,
15   respectively, for applying an electric field substan-
tially vertical to the first and second substrates across
the liquid crystal layer; a first polarizing plate and
a second polarizing plate each provided on an outer side
of respective one of the first and second substrates, the
20   first and second polarizing plates being arranged in a
crossed Nicols arrangement; and a phase difference
compensator. The liquid crystal layer in each pixel
region includes at least a first domain and a second domain
in which liquid crystal molecules are oriented in

different orientations. The phase difference compensator compensates for the refractive index anisotropy of the liquid crystal molecules in a substantially horizontal orientation with respect to the surfaces of the first and

5   second substrates.

In one embodiment of the invention, the first and second substrates are both transparent, and the phase difference compensator comprises a first phase difference

10   compensator provided between the first substrate and the first polarizing plate and a second phase difference compensator provided between the second substrate and the second polarizing plate.

15   In one embodiment of the invention, the first and second phase difference compensators each have a positive refractive index anisotropy, and phase-delay axes of the first and second phase difference compensators are substantially parallel to each other and substantially

20   perpendicular to a phase-delay axis of the liquid crystal layer in the absence of an applied voltage.

In one embodiment of the invention, a third phase difference compensator is further provided between the

first phase difference compensator and the first polarizing plate. The third phase difference compensator has a positive refractive index anisotropy. A phase-delay axis of the third phase difference compensator is substantially perpendicular to the first and second substrates.

In one embodiment of the invention, a fourth phase difference compensator is further provided between the second phase difference compensator and the second polarizing plate. The fourth phase difference compensator has a positive refractive index anisotropy. A phase-delay axis of the fourth phase difference compensator is substantially perpendicular to the first and second substrates.

In one embodiment of the invention, a fifth phase difference compensator is provided between the first phase difference compensator and the third phase difference compensator. A sixth phase difference compensator is provided between the second phase difference compensator and the fourth phase difference compensator. The fifth and sixth phase difference compensators each have a positive refractive index anisotropy. A phase-delay axis

of the fifth phase difference compensator is substantially perpendicular to a polarization axis of the first polarizing plate. A phase-delay axis of the sixth phase difference compensator is substantially perpendicular to

5   a polarization axis of the second polarizing plate.

In one embodiment of the invention, directors of the liquid crystal molecules in the first and second domains in the middle of the liquid crystal layer along

10   a thickness direction thereof rise in respective directions which are different from each other by about 180°. The directions are at about 45° with respect to the polarization axis of each of the first and second polarizing plates.

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In one embodiment of the invention, the liquid crystal molecules in the first and second domains are in a horizontal orientation.

20   In one embodiment of the invention, the liquid crystal molecules in the first and second domains are in a twist orientation.

In one embodiment of the invention, pre-tilt

angles of the liquid crystal molecules on the first and second substrates in the first domain are different from those in the second domain.

5   In one embodiment of the invention, pre-tilt angles of the liquid crystal molecules on the first and second substrates in the first domain are different from those in the second domain.

10   In one embodiment of the invention, the liquid crystal layer in each pixel region includes a plurality of the first domains and a plurality of the second domains, the number of the first domains being the same as the number of the second domains.

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In one embodiment of the invention, a total area of the first domains is equal to that of the second domains.

Thus, the invention described herein makes
20   possible the advantage of providing a liquid crystal display device having desirable viewing angle characteristics without sacrificing production efficiency and transmissivity.

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This and other advantages of the present invention will become apparent to those skilled in the art upon reading and understanding the following detailed description with reference to the accompanying figures.

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BRIEF DESCRIPTION OF THE DRAWINGS

Each of Figures **1A**, **1B** and **1C** is a view illustrating the definitions of the directions of main
10 axes which are used in the description of various examples of the present invention;

Figure **2A** is a perspective view illustrating a liquid crystal cell;

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Figure **2B** is a cross-sectional view illustrating the liquid crystal layer;

Figure **2C** is a plan view of the liquid crystal cell
20 as viewed from the viewer side;

Figure **2D** is a cross-sectional view of the liquid crystal cell along the line **5106** in Figure **2C**;

Figure **3A** and **3B** schematically illustrate a refractive index ellipse of a phase plate used in the description of various examples of the present invention;

5   Figure **4** is a perspective view schematically illustrating a liquid crystal display device according to an example of the present invention;

Figure **5A** is a cross-sectional view schematically
10   illustrating an orientation of liquid crystal molecules in the absence of an applied voltage;

Figure **5B** is a cross-sectional view schematically illustrating an orientation of liquid crystal molecules
15   in the presence of an applied voltage;

Figure **5C** is a graph showing a change in transmissivity in a region A observed while shifting the viewing angle, with the transmissivity in the normal
20   direction being used as a parameter;

Figure **6A** is a cross-sectional view schematically illustrating respective orientations of liquid crystal molecules in the liquid crystal regions A and B in a black

display;

Figure **6B** is a cross-sectional view schematically illustrating respective orientations of liquid crystal molecules in the liquid crystal regions A and B in a gray scale display;

Figure **6C** is a graph showing a change in transmissivity in the region A observed while shifting the viewing angle, with the transmissivity in the normal direction being used as a parameter;

Figure **6D** is a graph showing a change in transmissivity in the region B observed while shifting the viewing angle, with the transmissivity in the normal direction being used as a parameter;

Figure **6E** is a graph showing a change in transmissivity in the regions A and B as a whole observed while shifting the viewing angle, with the transmissivity in the normal direction being used as a parameter;

Figure **7A** illustrates a viewing angle dependency for one of the gray scale characteristics curves in

Figure 6E which is obtained for an applied voltage by which the transmissivity is about 50% from the normal direction;

Figure 7B illustrates the symmetry between the pixel division ratio (the ratio between the area of the region A and the area of the region B), showing the symmetry between the ratio between the area of the region A and the area of the region B and a gray scale level;

Figure 7C schematically illustrates a variation of the orientation division of a single pixel region according to the present invention;

Figure 7D schematically illustrates another variation of the orientation division of a single pixel region according to the present invention;

Figure 7E is a schematic view illustrating the reason that the viewing angle characteristics can be even more uniform by reducing the size of the unit of orientation division;

Figure 8A is a schematic cross-sectional view illustrating the liquid crystal molecules in a black

display in a normally black mode liquid crystal display device;

Figure **8B** is a diagram illustrating the relationship among the absorption axis of the polarizing plate, the orientation axis of the liquid crystal molecules, and the phase-delay axis of the phase plate, with which it is possible to obtain normally black characteristics in a liquid crystal cell having a horizontal orientation;

Figure **8C** is a graph showing a change in retardation value observed while shifting the viewing angle along the orientation of the liquid crystal molecules in a black display in a normally black mode liquid crystal display device;

Figure **8D** is a schematic cross-sectional view illustrating an orientation of liquid crystal molecules in a black display in a normally white mode liquid crystal display device;

Figure **8E** is a diagram illustrating the relationship among the absorption axis of the polarizing

plate and the orientation axis of the liquid crystal molecules, with which it is possible to obtain normally white characteristics in a liquid crystal cell having a horizontal orientation;

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Figure **8F** is a graph showing a change in retardation value observed while shifting the viewing angle along the orientation of the liquid crystal molecules in a black display in a normally white mode

10 liquid crystal display device;

Figure **8G** is a graph showing a change in retardation value observed while shifting the viewing angle along a direction perpendicular to the orientation

15 of the liquid crystal molecules in a black display in a normally black mode liquid crystal display device;

Figure **8H** is a graph showing a change in retardation value observed while shifting the viewing

20 angle along a direction perpendicular to the orientation of the liquid crystal molecules in a black display in a normally white mode liquid crystal display device;

Figure **9** is a diagram illustrating an improvement

in the viewing angle dependency of the contrast, showing the refractive index ellipse of the liquid crystal layer, the refractive index ellipses of a group of phase plates, and the polarization axis of incident linearly-polarized light;

Figure **10A** is a diagram illustrating a refractive index ellipse having a positive uniaxial refractive index anisotropy;

Figure **10B** is a diagram for illustrating transmitted light when linearly-polarized light which forms an angle of about 45° with respect to the phase-delay axis is incident upon a refractive index ellipse in a direction normal to a display plane;

Figure **10C** is a diagram for illustrating transmitted light when linearly-polarized light which forms an angle of about 45° with respect to the phase-delay axis is incident upon a refractive index ellipse having a positive uniaxial ellipse anisotropy in a direction inclined along the phase-delay axis from the normal to a plane, which includes the phase-delay axis thereof;

Figure **10D** is a diagram for illustrating trans-
mitted light when linearly-polarized light is incident
upon a refractive index ellipse having a positive uniaxial
ellipse anisotropy, in a direction along the phase-delay

5   axis thereof;

Figure **10E** is a diagram for illustrating trans-
mitted light when linearly-polarized light is incident
upon a refractive index ellipse having a positive uniaxial

10   ellipse anisotropy, in a direction inclined from the
phase-delay axis thereof;

Figure **11A** is a schematic diagram illustrating a
liquid crystal cell of a liquid crystal display device

15   of the present invention, showing the rubbing direction;

Figure **11B** is a schematic diagram illustrating a
liquid crystal cell of a liquid crystal display device
of the present invention, showing an orientation of the

20   liquid crystal molecules along the cell thickness
direction after the rubbing process as illustrated in
Figure **11A**;

Figure **11C** is a schematic diagram illustrating a

liquid crystal cell of a liquid crystal display device of the present invention, showing an orientation of the liquid crystal molecules along the cell thickness direction after the rubbing process as illustrated in

5   Figure **11A** and an orientation division process;

Figure **12** is an isocontrast diagram for a liquid crystal display device according to an example of the present invention;

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Figure **13** is a perspective view schematically illustrating a liquid crystal display device according to a comparative example;

15   Figure **14** is an isocontrast diagram for a liquid crystal display device according to a comparative example;

Figure **15** is a graph showing a preferred range of

20   retardation (in the X_REF direction) of a phase difference compensator of a liquid crystal display device according to an example of the present invention;

Figure **16** is a graph showing a preferred range of

retardation (in the Y_REF direction) of a phase difference compensator of a liquid crystal display device according to an example of the present invention;

5   Figure **17** is a graph showing a preferred range of retardation (average value) of a phase difference compensator of a liquid crystal display device according to an example of the present invention;

10   Figure **18** is a perspective view schematically illustrating a liquid crystal display device according to an example of the present invention;

Figure **19** is a graph showing the relationship

15 between the retardation of a 45° phase plate and the transmissivity in a black display;

Figure **20** is a graph illustrating the relation-ship between the transmissivity and the applied voltage

20 in a liquid crystal display device according to an example of the present invention;

Figure **21A** is a graph illustrating the viewing angle dependency (along a direction parallel to the X_REF

axis) of the transmissivity for various gray scale levels in an 8-gray-scale-level display produced by a liquid crystal display device according to an example of the present invention;

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Figure **21B** is a graph illustrating the viewing angle dependency (along a direction parallel to the X_REF±45° axis) of the transmissivity for various gray scale levels in an 8-gray-scale-level display produced by a liquid crystal display device according to an example

10 of the present invention;

Figure **21C** is a graph illustrating the viewing angle dependency (along a direction parallel to the Y_REF axis) of the transmissivity for various gray scale levels

15 in an 8-gray-scale-level display produced by a liquid crystal display device according to an example of the present invention;

20 Figure **22** is an isocontrast diagram for a liquid crystal display device according to an example of the present invention;

Figure **23** is a diagram schematically illustrating

a structure of a liquid crystal display device according to an example of the present invention;

Figure **24** is a diagram schematically illustrating
5   a structure of a liquid crystal display device according to another example of the present invention;

Figure **25** is a diagram schematically illustrating a structure of a liquid crystal display device according
10   to another example of the present invention;

Figure **26** is a diagram schematically illustrating a structure of a liquid crystal display device according to another example of the present invention;

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Figure **27** is a graph illustrating the relation-ship between the transmissivity and the applied voltage in a liquid crystal display device according to an example of the present invention;

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Figure **28A** is a graph illustrating the viewing angle dependency (along a direction parallel to the X_REF axis) of the transmissivity for various gray scale levels in an 8-gray-scale-level display produced by a liquid

crystal display device according to an example of the present invention;

Figure **28B** is a graph illustrating the viewing angle dependency (along a direction parallel to the X_REF±45° axis) of the transmissivity for various gray scale levels in an 8-gray-scale-level display produced by a liquid crystal display device according to an example of the present invention;

Figure **28C** is a graph illustrating the viewing angle dependency (along a direction parallel to the Y_REF axis) of the transmissivity for various gray scale levels in an 8-gray-scale-level display produced by a liquid crystal display device according to an example of the present invention;

Figure **29** is an isocontrast diagram for a liquid crystal display device according to an example of the present invention;

Figure **30** is a diagram schematically illustrating a structure of a liquid crystal display device according to another example of the present invention;

Figure **31** is a diagram illustrating a structure of a liquid crystal display device in Examples 15, 15-A to 15-D, Comparative Examples 13-E to 13-H, and Example 14.

Figure **32** is a graph illustrating the relationship between the transmissivity as viewed from the normal direction and the applied voltage in a liquid crystal display device according to Example 15;

Figure **33** is a graph illustrating a change in transmissivity for various gray scale levels with respect to a change in the viewing angle along the X_REF axis direction in an 8-gray-scale-level display produced by a liquid crystal display device according to Example 15;

Figure **34** is a graph illustrating a change in transmissivity for various gray scale levels with respect to a change in the viewing angle along the X_REF+45° axis direction in an 8-gray-scale-level display produced by a liquid crystal display device according to Example 15;

Figure **35** is a graph illustrating a change in

transmissivity for various gray scale levels with respect to a change in the viewing angle along the X_REF-45° axis direction in an 8-gray-scale-level display produced by a liquid crystal display device according to Example 15;

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Figure **36** is a graph illustrating a change in transmissivity for various gray scale levels with respect to a change in the viewing angle along the Y_REF axis direction in an 8-gray-scale-level display produced by a liquid crystal display device according to Example 15;

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Figure **37** is an isocontrast contour curve for a liquid crystal display device according to Example 15;

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Figure **38** is a graph showing the optimal value of the retardation value d · (na-nb) (R1) of the phase difference compensators **2402** and **2403** with respect to the retardation value d·Δn(RLC) of the liquid crystal cell according to Example 15;

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Figure **39** is a graph showing the optimal value of the retardation value d · (na-nb) (R2a) of the phase difference compensators **2404** and **2405** with respect to the retardation value d·(na-nb) (R1) of the phase difference

compensators **2402** and **2403** according to Example 15;

Figure **40** is a graph showing the optimal value of the retardation value -d·(na-nc) (-R2b) of the phase difference compensators **2404** and **2405** with respect to the retardation value d·(na-nb) (R2a) of the phase difference compensators **2404** and **2405** according to Example 15;

Figure **41** is an isocontrast contour curve for a liquid crystal display device according to Example 15-A;

Figure **42** is an isocontrast contour curve for a liquid crystal display device according to Example 15-B;

Figure **43** is an isocontrast contour curve for a liquid crystal display device according to Example 15-C;

Figure **44** is an isocontrast contour curve for a liquid crystal display device according to Example 15-D;

Figure **45** is an isocontrast contour curve for a liquid crystal display device according to Example 15-E;

Figure **46** is an isocontrast contour curve for a

liquid crystal display device according to Example 15-F;

Figure **47** is an isocontrast contour curve for a liquid crystal display device according to Example 15-G;

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Figure **48** is an isocontrast contour curve for a liquid crystal display device according to Example 15-H;

Figure **49** is a graph illustrating the relation-

10 ship between the transmissivity as viewed from the normal direction and the applied voltage in a liquid crystal display device according to Example 16;

Figure **50** is an isocontrast contour curve for a

15 liquid crystal display device according to Example 16;

Figure **51** is a diagram illustrating the transi-tion of polarization of light passing through a liquid crystal display device according to Example 16 in a

20 direction parallel to the normal to the surface of the liquid crystal cell with an applied voltage of 0 V;

Figure **52** is a diagram illustrating the transi-tion of polarization of light passing through a liquid

crystal display device according to Example 11 in a direction parallel to the normal to the surface of the liquid crystal cell with an applied voltage of 0 V;

5   Each of Figures 53A and 53B is a diagram illustrating the transition of polarization of light passing through a liquid crystal display device according to Example 15 in a direction parallel to the normal to the surface of the liquid crystal cell with an applied

10   voltage of 0 V;

Figure 54 is a diagram used for showing that there exist a countless number of parameters for the liquid crystal cell, the phase difference compensators and the

15   polarizers with which it is possible to obtain normally black electro-optical characteristics using a liquid crystal cell having a substantially horizontal orientation in the absence of an applied voltage; and

20   Figure 55 is a schematic diagram illustrating a liquid crystal display device as disclosed in Japanese Laid-Open Publication No. 5-289097.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The first part of the present invention will be described below, which comprises Examples 1 and 2.

First, definitions for parameters characterizing a liquid crystal layer, a polarizing plate and a phase plate used commonly in Embodiments 1 and 2 will be described.

Each of the parameters, particularly angles, are defined based on an XYZ rectangular coordinate system which is appropriately assumed on a liquid crystal panel. As illustrated in Figures 1A-1C, the reference coordinate system only needs to have the XY plane thereof being parallel to the liquid crystal panel, and the direction of the X and Y axes is not limited to any particular direction (e.g., it may be any of those illustrated in Figures 1A-1C). Note, however, that for any particular liquid crystal display device, a set of axes is assumed commonly for the liquid crystal layer, the polarizing plate, and the phase plate thereof. In the following description, the main axes of the reference coordinate system are denoted by "X_REF", "Y_REF", and "Z_REF", respectively.

The parameters characterizing the orientation of the liquid crystal molecules in the liquid crystal layer will be described with reference to Figures 2A-2D.

5   Figure **2A** is a perspective view illustrating a liquid crystal cell. For the sake of simplicity, a single domain across which orientation of liquid crystal molecules is uniform will be described below. Where a pixel region is divided into a plurality of domains having different

10 orientations, parameters characterizing the liquid crystal layer for each domain include: ① the retardation value of the liquid crystal layer; ② the twist angle of the liquid crystal layer; and ③ the orientation of the liquid crystal molecules (those located in the middle of

15 the liquid crystal layer along the thickness thereof) (i.e., the phase-delay axis of the liquid crystal layer).

Figure 2B is a cross-sectional view illustrating a liquid crystal layer. The retardation value of the

20 liquid crystal layer is defined as a product $d_{lc} \cdot \Delta n$ of the refractive index anisotropy Δn of a liquid crystal material **5103** of the liquid crystal layer interposed between substrates **5101** and **5102** and the distance d_{lc} of the substrate **5101** (e.g., a substrate on which a color

filter is provided) and the substrate **5102** (e.g., a substrate on which a TFT array is provided) (the distance d_{lc} corresponds to the thickness of the liquid crystal layer = the cell gap).

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Figure **2C** is a plan view of the liquid crystal cell as viewed from the viewer side. A line **5104** is parallel to the long axis of a liquid crystal molecule adjacent to the light source side substrate **5102**, and a line **5105**

10 is parallel to the long axis of another liquid crystal molecule adjacent to the viewer side substrate **5101**. For the sake of simplicity, it is assumed in the following description that the twist angle of the liquid crystal molecules is about 90° or less. Herein, the twist angle

15 of the liquid crystal layer is defined as an angle obtained by rotating the line **5104** to meet the line **5105**, wherein a positive twist angle is obtained by rotating the line **5104** counterclockwise. The angle as defined above is denoted by "θ_{twist}" in the figure.

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The orientation of the liquid crystal layer is defined as follows. Referring again to Figure **2C**, a line **5106** is shown to equiangularly bisect the angle θ_{twist}. The line **5106** represents a direction in which a liquid

crystal molecule located in the middle of the liquid

crystal layer along the thickness thereof rises in re-

sponse to an applied electric field. This direction is

called the orientation or phase-delay axis of the liquid

5   crystal layer. Herein, only some of the liquid crystal

molecules present in the liquid crystal layer will be

considered, whose long axes are substantially parallel

to the line **5106** in the presence of a voltage which gives

the liquid crystal layer an intermediate transmissivity

10   (a gray scale voltage). Figure **2D** is a cross-sectional

view of the liquid crystal cell along the line **5106**.

Figure **2C** further shows an arrow **5107** parallel to the

line 5106. The tip of the arrow **5107** corresponds to a

rising tip (end) of a liquid crystal molecule. Then, the

15   orientation of the liquid crystal layer is defined as an

angle β between the arrow **5107** and the reference axis

X_REF, wherein a positive orientation is obtained by

rotating the reference axis X_REF counterclockwise.

20   A parameter for a polarizing plate is a direction

(angle) of the polarization axis (transmission axis)

thereof. Definition of the direction of the polarization

axis will be described (not shown in the figures). The

direction of the polarization axis is defined as an angle

between the polarization axis and the reference axis X_REF, wherein a positive direction is obtained by rotating the reference axis X_REF counterclockwise. Of course, polarization axis directions α, $\alpha+180°$, and $\alpha-180°$ all denote an equivalent polarizing plate.

Parameters for a phase plate are defined as follows. Parameters for a phase plate include: ① the in-plane retardation value (in a plane parallel to the display plane); ② the retardation value along the thickness direction (in a direction vertical to the liquid crystal display plane); ③ the angle of the main axis a (the angle between X_REF and the main axis a); ④ the parameter RL (the ratio of the retardation value along the thickness direction with respect to the retardation value of the liquid crystal layer); and ⑤ the parameter NZ (the ratio of the retardation value along the thickness direction with respect to the in-plane retardation value).

Figures **3A** and **3B** show a refractive index ellipse of the phase plate. The three main axes of the refractive index ellipse of the phase plate used in the examples of the present invention are denoted by a, b and c, respectively. The main axes a, b and c together form a

rectangular coordinate system. The main axes a and b lie in a plane parallel to the phase plate surface, i.e., in a plane parallel to the display plane. The refractive index values along the main axes a, b and c are denoted by na, nb and nc, respectively. The thickness of the phase plate is denoted by d. Then,

① The in-plane retardation of the phase plate is defined as $d \cdot (na-nb)$;

② The retardation along the thickness direction is defined as $d \cdot (na-nc)$;

③ The angle of the main axis a is defined as an angle γ between the reference axis X_REF and the main axis a, wherein a positive angle is obtained by rotating the reference axis X_REF counterclockwise;

④ The parameter RL is defined as $d \cdot (na-nc)/(d_{lc} \cdot \Delta n)$; and

⑤ The parameter NZ is defined as $(na-nc)/(na-nb)$.

The embodiments of the present invention will be described below with reference to the figures. First, the principle of operation of the liquid crystal display device according to the present invention will be described with reference to Figure **4**.

Figure 4 schematically illustrates a liquid crystal display device 100 of the present invention. Figure 4 illustrates a transmission-type liquid crystal display device.

The liquid crystal display device 100 includes: a liquid crystal layer 101; a pair of electrodes 100a and 100b for applying a voltage across the liquid crystal layer 101; a pair of phase plates 102 and 103 provided on the respective sides of the liquid crystal layer 101 (the phase plate may of course be of any type, including a phase difference compensation film, a liquid crystal cell, and the like, as long as it has an appropriate refractive index anisotropy); another pair of phase plates 104 and 105 provided on the phase plates 102 and 103, respectively; and a pair of polarizing plates 108 and 109 provided in a crossed Nicols arrangement so as to interpose the above-listed elements therebetween. The arrows in the polarizing plates 108 and 109 illustrated in Figure 4 denote the respective polarization axes (transmission axes) thereof.

Figure 4 illustrates the liquid crystal layer 101

corresponding to one pixel, and the orientation of the liquid crystal molecules therein in the absence of an applied voltage. An ellipse in Figure **4** schematically represents a liquid crystal molecule. As the liquid

5   crystal material, a nematic liquid crystal material having a positive dielectric anisotropy (hereinafter, referred to simply as the "Np liquid crystal material") may be used. The liquid crystal molecules are oriented substantially parallel to the surfaces of the pair of substrates (not

10   shown) and electrodes. Electrodes **100a** and **100b** are provided on a side of the pair of substrates facing the liquid crystal layer **101** so as to interpose the liquid crystal layer **101** therebetween. By applying a voltage between the electrodes **100a** and **100b**, an electric field

15   is applied across the liquid crystal layer **101** in a direction substantially vertical to the substrate sur- face.

As illustrated in Figure **4**, the liquid crystal

20   layer **101** for each axis region includes a first do- main **101a** and a second domain **101b** having different orientations from each other. In the example illustrated in Figure **4**, the director of the liquid crystal molecules in the first domain **101a** and the director of the liquid

crystal molecules in the second domain **101b** are oriented

to form an azimuth angle of about 180° with respect to

each other. The orientation of the liquid crystal

molecules is controlled so that when a voltage is applied

5   between the electrodes **100a** and **100b**, the liquid crystal

molecules in the first domain **101a** rise in the clockwise

direction while those in the second domain **101b** rise in

the counterclockwise direction, i.e., the molecules in

the different domains rise in opposite directions. Such

10   an orientation of the directors of the liquid crystal

molecules can be achieved by using any orientation control

technique known in the art using an alignment film. When

a plurality of such first domains and a plurality of such

second domains (in which the director is oriented in a

15   direction different from that in the first domains by about

180°) are provided in each axis region, the viewing angle

characteristics can be even more uniform.

Thus, when viewing a gray scale image on the liquid

20   crystal display device **100** with pixels each divided into

a plurality of regions having different orientations, the

change in the brightness the image experienced while

inclining the viewing angle from the direction normal to

the display plane (hereinafter, also referred to as the

"normal" or the "normal direction") toward the first domain **101a** is symmetric with that experienced while inclining the viewing angle toward the second domain **101b**. It is preferred that the area of the first domain **101a** is substantially equal to that of the second domain **101b**. The areas of respective domains do not have to be equal to one another for each pixel region, but substantially the same effect can be obtained when the total area of the first domains **101a** is substantially equal to the total area of the second domains **101b** for the entire display plane. Thus, the way to achieve the orientation division is not limited to that described above.

As illustrated in Figure **4**, the director of the liquid crystal molecules in the first domain **101a** and the director of the liquid crystal molecules in the second domain **101b** are oriented to form an azimuth angle of about 180° with respect to each other. This direction is parallel to the direction indicted by an arrow **609** in Figure **4**. In this specification, the direction **609** is assumed to be along the phase-delay axis of the liquid crystal layer in the absence of an applied voltage. Generally, the direction of the phase-delay axis of a liquid crystal layer in the absence of an applied voltage

is defined as an azimuth angle in which liquid crystal molecules in the middle of the liquid crystal layer along the thickness thereof rise in response to an applied voltage. This definition can be applied not only to a liquid crystal layer in which the liquid crystal molecules are oriented horizontally to the substrate surface (including anti-parallel orientation), but also to a liquid crystal layer in which the liquid crystal molecules are in a twist orientation.

The first phase difference compensator **102** and the second phase difference compensator **103** typically have a positive uniaxial refractive index anisotropy, and the axis of the refractive index ellipse which has the maximum refractive index (i.e., the phase-delay axis) (the direction indicated by an arrow **125** or **126** in Figure **4**) is arranged to be parallel to the substrate surface and perpendicular to the phase-delay axis of the liquid crystal layer **101** in the absence of an applied voltage. Therefore, it is possible to control the light leakage due to the refractive index anisotropy of the liquid crystal molecules in the absence of an applied voltage and thus to obtain a desirable black display (or desirable normally black characteristics).

The third phase difference compensators **104** and **105** typically have a biaxial refractive index anisotropy, and the phase-delay axis (the direction indicated by an arrow **121** or **122** in Figure **4**) is arranged to be parallel to the direction normal to the substrate surface so as to compensate for the change in transmissivity associated with the change in viewing angle. Moreover, each of the third phase difference compensators **104** and **105** is arranged so that one of the main axes of the refractive index ellipse thereof parallel to the substrate surface which has a larger refractive index is perpendicular to the polarization axis of one of the polarizing plates closer to that phase difference compensator. Thus, it is possible to compensate for the rotation of the polarization axis of elliptically-polarized light, and further to provide a display with desirable viewing angle characteristics. Alternatively, only one of the third phase difference compensators **104** and **105** may be provided.

The elements of the present invention will be described in greater detail below.

Nematic Liquid Crystal Material Having Positive

Dielectric Anisotropy: Np Liquid Crystal Material

As in a liquid crystal display device of a widely-used TN mode, the present invention employs a substrate which has been subjected to a horizontal alignment treatment, and an Np liquid crystal material. Therefore, the time required for a liquid crystal injection process can be reduced to about half of that required in the liquid crystal display device of Japanese Laid-Open Publication No. 7-28068 which employs a substrate which has been subjected to a vertical alignment treatment and an Nn liquid crystal material. Generally, an Np liquid crystal material has a lower viscosity than that of an Nn liquid crystal material, and a substrate which has been subjected to a horizontal alignment treatment has a higher wettability for a liquid crystal material than that of a substrate which has been subjected to a vertical alignment treatment. These factors together provide a multiplier effect of enabling a high-speed liquid crystal injection. The liquid crystal injection process has a significant proportion in the total amount of time required for the production of a liquid crystal display device. Therefore, the substantial reduction in this process leads to a substantial improvement in the production efficiency of the liquid

crystal display device.

Vertical Electric Field

According to the present invention, a pair of electrodes arranged to interpose a liquid crystal layer therebetween are used to apply a vertical (to the substrate) electric field across the liquid crystal layer so as to drive the liquid crystal molecules. Therefore, it is possible to realize an aperture ratio comparable to that of a conventional TN mode liquid crystal display device. Thus, it is not necessary to provide an opaque electrode within the pixel region as in the IPS mode, whereby it is possible to obtain a liquid crystal display device having a larger aperture ratio than a liquid crystal display device of the IPS mode.

Orientation Division

Including the TN mode which is currently widely used in the art, a liquid crystal display device in which the transmissivity is varied by moving the liquid crystal molecules in the thickness direction of the liquid crystal layer has a display brightness that is substantially dependent upon the viewing angle (inferior viewing angle characteristics). This will be further described with

reference to Figures **5A**, **5B** and **5C**. Figures **5A** and **5B** schematically illustrate a liquid crystal display device having a liquid crystal layer **203** having a twist orientation. Referring to Figures **5A** and **5B**, a pair of electrodes **201** and **202** are provided between a pair of polarizing plates **206** and **207** which are arranged in a crossed Nicols arrangement. The liquid crystal layer **203** is interposed between the electrodes **201** and **202**. Figures **5A** and **5B** are drawn so that a liquid crystal molecule in the middle of the liquid crystal layer **203** along the thickness thereof has a long axis along the plane of the figures (such a molecule appears to be the longest). Figures **5A** and **5B** correspond to the absence and the presence of an applied voltage.

As illustrated in Figure **5A**, the liquid crystal molecule **203a** in the middle of the liquid crystal layer **203** along the thickness thereof is oriented substantially parallel to the substrate surface. This state appears to be the same from a viewing angle **204** and from a viewing angle **205**. When a gray scale voltage is applied as in Figure **5B**, different states are viewed from different viewing angles. This is due to the liquid crystal molecules having a positive uniaxial refractive

index anisotropy (a cigar-shaped refractive index el-
lipse). In response to an applied voltage, a liquid
crystal molecule 203b rises in a direction which is
defined by the pre-tilt angle thereof (in the counter-
5   clockwise direction in this example). When the liquid
crystal molecule 203b is viewed from the viewing angle 204
(along the long axis of the molecule 203b), the refractive
index anisotropy of the cigar-shaped refractive index
ellipse disappears (the molecule 203b is viewed to have
10   a circular shape). When the liquid crystal molecule 203b
is viewed from the viewing angle 205, the refractive index
anisotropy peaks.

Therefore, when the liquid crystal molecules 203b
15   in the liquid crystal cell are viewed from the viewing
angle 204, a majority of the molecules are viewed to have
a circular shape, i.e., the refractive index anisotropy
of the liquid crystal layer decreases. Thus, line-
arly-polarized light having passed through the polarizing
20   plate 206 reaches the polarizing plate 207 without having
been substantially altered by the liquid crystal layer 203,
and then is blocked by the polarizing plate 207 whose
polarization axis is perpendicular to that of the
polarizing plate 206, thereby reducing the

transmissivity. When the liquid crystal molecules **203b** in the liquid crystal cell are viewed from the viewing angle **205**, a majority of the molecules are viewed to have an elongated shape, i.e., the refractive index anisotropy of the liquid crystal layer **203** peaks. Therefore, polarized light having passed through the polarizing plate **206** has the polarization altered by the liquid crystal layer **203** so that the maximum amount of light passes through the polarizing plate **207**.

As a result, the brightness substantially changes while inclining the viewing angle between the direction in which the liquid crystal molecules rise (the viewing angle **204** in Figure 5B) and the opposite direction (the viewing angle **205** in Figure 5B), as illustrated in Figure 5C. Typically, the viewing angles **204** and **205** are set to correspond to the lower side (the 6 o'clock direction) and the upper side (the 12 o'clock direction) of the panel. Figure 5C illustrates various transmissivity curves for various applied voltages.

Thus, in the conventional TN mode, the brightness substantially varies as the viewing angle is inclined along the orientation of the liquid crystal molecules.

As can be seen from the above description, such asymmetry in the gray scale characteristics is seen not only in the TN mode, but also commonly in other various display modes where the liquid crystal molecules are moved along the

5   thickness of the liquid crystal cell, and where orientation division is not employed.

By dividing a pixel into a plurality of regions having different orientations, it is possible to improve

10   the asymmetry in the gray scale characteristics with respect to the viewing angle, and to obtain desirable gray scale characteristics (viewing angle characteristics) which are symmetric in the up-down direction and in the left-right direction. This will be further described

15   with reference to Figures **6A-6E**. For example, each pixel region is divided into two regions (first and second domains) A and B in which the liquid crystal molecules rise in response to an applied voltage in directions different from each other by about 180°, as illustrated

20   in Figures **6A** and **6B**. In the absence of an applied voltage, the liquid crystal molecules in both regions are oriented substantially parallel to the substrate surface, as illustrated in Figure **6A** (the pre-tilt angle is ignored herein for simplicity). When a gray scale voltage is

applied, a liquid crystal molecule 303a in the region A rise in the counterclockwise direction and a liquid crystal molecule 303b in the region B rises in the clockwise direction, as illustrated in Figure 6B (the rising direction is dictated by the pre-tilt angle). As described above, the gray scale characteristics in the regions A and B are dependent upon the viewing angles 304 and 305, as illustrated in Figures 6C and 6D. The regions A and B are present in one pixel region, and therefore the gray scale characteristics of the pixel region as a whole are the average of the respective gray scale characteristics illustrated in Figures 6C and 6D with the ratio between the respective areas of the regions A and B being taken into consideration. Thus, by setting the ratio between the area SA of the region A and the area SB of the region B to 1:1, it is possible to obtain gray scale characteristics that are symmetric for the viewing angles 304 and 305, as illustrated in Figure 6E.

Next, the ratio SA:SB and the resulting gray scale characteristics will be described so as to estimate a range in which the orientation division effect can be obtained. Figure 7A illustrates a viewing angle dependency for one of the gray scale characteristics curves in Figure 6E

which is obtained for an applied voltage by which the transmissivity is about 50% from the normal direction. For the symmetry in the up-down direction, Figure **7B** illustrates the relationship between the ratio TA/TB and
5   the ratio SA/(SA+SB) between the areas SA and SB of the regions A and B. TA and TB denote transmissivities obtained in directions respectively at 50° in the viewing angles **304** (toward the upper side of the panel) and **305** (toward the lower side of the panel) as illustrated in
10   Figures **6A** and **6B**. It can be seen from Figure **7B** that the gray scale characteristics become symmetric in the up-down direction (i.e., TA/TB = about 1) when the ratio SA/(SA+SB) is about 0.5.

15   The number of divided regions having different orientations is not limited to two, but may be any number as long as the total area of one region having a liquid crystal molecule rising direction and the total area of another region having the opposite liquid crystal molecule
20   rising direction are substantially equal to each other for the entire display plane. In view of the display uniformity, it is preferred that a divided region has a small area, and each pixel region is divided into two or more domains having different orientations. Moreover,

each pixel region may have a plurality of regions A and a plurality of regions B arranged in an alternate manner, as illustrated in Figures 7C and 7D. By reducing the size of the unit of orientation division, e.g., by providing

5   a plurality of regions A and a plurality of regions B in each pixel region, the viewing angle characteristics can be even more uniform. This is because the proportion of light passing through both of the regions A and B (indicated by an arrow 401) with respect to light passing

10   through only one of the regions A and B (indicated by an arrow 402A or 402B) increases when the liquid crystal display device is viewed from an inclined direction, as illustrated in Figure 7E.

15   <u>Normally Black Mode and Improvement of Contrast Ratio</u>
     The present invention is in a normally black mode in which a black display is produced in the absence of an applied voltage, and employs a third phase difference compensator so as to improve the viewing angle

20   characteristics. The viewing angle characteristics as used herein refer to changes in displayed images observed when inclining the viewing angle from a direction vertical to the display plane of a liquid crystal display device toward an inclined viewing angle. Such changes observed

in displayed images include a change in gray scale, a change in contrast ratio, a change in color, and the like. The change in gray scale can be improved by the orientation division as described above. A way to control the change

5   in contrast ratio will be first described below, and a way to realize a normally black mode with the first and second phase difference compensators will also be described. Then, an effect of suppressing the change in contrast ratio (or an effect of improving the viewing angle

10   dependency of the contrast ratio) will be described, which is provided by a combination of the first and second phase difference compensators with the third phase difference compensator. Finally, for comparison purposes, the difficulty in controlling the change in contrast ratio

15   in a normally white mode will be described.

A contrast ratio (CR) is defined as a value obtained by dividing the maximum transmissivity (the transmissivity in a white display) by the minimum

20   transmissivity (the transmissivity in a black display). In an ordinary liquid crystal display device, the change in transmissivity associated with an inclined viewing angle is greater in a black display than in a white display. Therefore, the change in transmissivity in a black display

(also known as "degradation of black display") associated with an inclined viewing angle should be improved in order to improve the viewing angle dependency of the contrast ratio.

5

In order to realize a normally black mode, it is effective to compensate for (cancel out) the refractive index anisotropy of a liquid crystal layer in which the liquid crystal molecules are oriented parallel to the

10 substrate surface in the absence of an applied voltage. According to the present invention, the compensation is provided by the phase plates **102** and **103** as illustrated in Figure **4**. In the example illustrated in Figure **8A**, phase plates **502** and **503** provide the same function as that

15 of the phase plates **102** and **103**. As illustrated in Figure **8A**, the liquid crystal layer of the present invention has a substantially horizontal orientation in the absence of an applied voltage. When the liquid crystal layer is viewed from the direction normal to the

20 liquid crystal display device, the maximum refractive index results along a direction (orientation) indicated by an arrow **508** in Figure **8B**, and the minimum refractive index results along a direction perpendicular thereto. In the present invention, the value obtained by

multiplying the difference between the maximum and minimum
refractive indexes by the thickness of the liquid crystal
layer, i.e., the retardation value of the liquid crystal
layer, is set to be about 250 nm (in a range from about

5   50 nm to about 500 nm). Herein, the first and second
phase plates **502** and **503** each having a positive uniaxial
refractive index anisotropy are used in order to realize
the normally black mode characteristics. More specifi-
cally, the retardation value of the phase plates **502** and

10   **503** is set to be about 1/2 of that of the liquid crystal
layer, i.e., about 125 nm, and the phase-delay axes
thereof are aligned with the arrows **509** and **510**
(perpendicular to the arrow **508**), respectively. In this
way, it is possible to cancel out the birefringence effect

15   due to the liquid crystal layer in the absence of an applied
voltage by the first and second phase plates.

In the case of a liquid crystal display device with
such an orientation division according to the present

20   invention, the phase difference compensation to improve
degradation of the black display is more easily done in
a normally black mode than in a normally white mode. As
a result, it is possible to provide a liquid crystal
display device in a normally black mode with a desirable

viewing angle dependency of the contrast ratio, whereas it is more difficult to provide such a liquid crystal display device in a normally white mode. This will be further described below.

5

As illustrated in Figure **8A**, in a liquid crystal display device which produces a black display in the absence of an applied voltage, the region A and the region B of the liquid crystal layer have substantially

10   the same orientation, i.e., parallel to the substrate surface. In other words, the regions A and B have substantially the same orientation, while one of the main axes of the refractive index ellipse representing the liquid crystal layer is parallel to the normal to the

15   substrate, with the other two main axes lying in a plane parallel to the substrate surface. Moreover, one of the main axes of the refractive index ellipse representing the first and second phase plates is also parallel to the normal to the substrate, with the other two main axes lying

20   in a plane parallel to the substrate surface.

Figure **8C** illustrates a change in retardation value for the regions A and B which is observed when shifting the viewing angle between the direction indicated

by the arrow **520** and the direction indicated by the arrow **521** in Figure **8B**. Figure **8G** illustrates a change in retardation value observed when shifting the viewing angle between the direction indicated by the arrow **522**

5 and the direction indicated by the arrow **523** in Figure **8B**.

The viewing angle dependency of the retardation value in region A is equal to that in region B. In addition, the limit of the retardation value (the bottom

10 of the curve in Figures **8C** and **8G**) appears at the same degree for any of the viewing angles **520**, **521**, **522** and **523** (at 0° in the figures). The change in retardation value can be compensated for in order to control the degradation of black display associated with the change

15 in viewing angle (the viewing angle dependency of the contrast ratio).

As can be seen from the characteristics of the change in the retardation value, in the liquid crystal

20 display device of the present invention, it is possible to provide phase difference compensation by the same phase difference compensator (the third phase plate) for both of the regions A and B. In addition, it is possible to use, as the third phase difference compensator, a phase

plate in which one of the main axes of the refractive index
ellipse is parallel to the normal to the surface of the
phase plate, with the other two main axes lying in a plane
parallel to the surface of the phase plate. A phase plate

5   having such characteristics can be easily and inexpen-
sively produced by a conventional method such as the
drawing method. A main feature of the present invention
is to employ a normally black mode in a liquid crystal
display device with such an orientation division, and to

10   use one or more (third) phase plates having the same
characteristics for any of the divided regions, so as to
control the viewing angle dependency of the change in
contrast ratio.

15   In the case of a normally white mode as illustrated
in Figure **8D** where a black display is produced in the
presence of an applied voltage, the regions A and B have
different orientations when producing a black display,
and the main axis of the refractive index ellipse

20   representing the liquid crystal layer is inclined from
the normal to the substrate. Figure **8F** illustrates the
change in retardation value for the regions A and B when
viewing the liquid crystal display device in the normally
white mode as illustrated in Figure **8E** while shifting the

viewing angle between the direction indicated by the arrow **520** and the direction indicated by the arrow **521**, and Figure **8H** illustrates a change in retardation value while shifting the viewing angle between the direction indicated by the arrow **522** and the direction indicated by the arrow **523**.

Referring to Figure **8F**, the changes in retardation value between the directions **520** and **521** for the regions A and B, respectively, are substantially different from each other. For example, the retardation value for the region A takes the minimum value when it is viewed from a direction indicated by the arrow **520**, whereas the retardation value for the region B takes the minimum value when it is viewed from direction indicated by the arrow **521**.

Based on the above, in order to improve the degradation of the black display in the liquid crystal display device, as illustrated in Figure **8D**, it is required to provide different phase difference compensators for the regions A and B, respectively. As the regions A and B are obtained by dividing one pixel region and therefore have very small areas, it is practically very

difficult to produce such phase difference compensators which improve the degradation of the black display.

Viewing Angle Compensation by Third Phase Difference
5   Compensator

As described above, by employing a phase difference compensator in which one of the main axes of the refractive index ellipse is parallel to the normal to the surface of the phase plate, with the other two main
10   axes lying in a plane parallel to the surface of the phase plate, it is possible to improve the change in retardation values of the liquid crystal layer **101**, the first phase difference compensator **102**, and the second phase difference compensator **103**, as illustrated in Figure **4**,
15   associated with an inclined viewing angle, i.e., degradation of black display. According to the present invention, the degradation of black display is compensated for by the third phase difference compensator.

20   How the degradation of black display can be compensated for by the third phase difference compensator will be described with reference to Figure **9**, with particular attention to the angular change in the refractive index anisotropy of the liquid crystal

molecules and that of the phase difference compensator.
Figure **9** illustrates refractive index ellipses of the
liquid crystal layer and the phase difference compensators
used in the present invention. In particular, Figure **9**

5   illustrates a refractive index ellipse **601** of the liquid
crystal layer **101** as illustrated in Figure **4**, and
refractive index ellipses **602** and **603** of the first and
second phase difference compensators **102** and **103**. Each
of the refractive index ellipses has positive uniaxiality,

10   and the optical axis thereof lies in a plane parallel to
the surface of the liquid crystal display device. The
refractive index ellipses **604** and **605** of the third phase
difference compensators **104** and **105** lie in a plane
parallel to the normal to the surface of the liquid crystal

15   display device.

The change in refractive index observed when
viewing a refractive index ellipse **706** (a phase-delay
axis **704** and an ellipse **705** perpendicular thereto) will

20   be described with reference to Figures **10A-10E**. First,
a case where the liquid crystal display device is viewed
from the normal direction will be discussed. The
refractive index anisotropy contributing to the
birefringence of the liquid crystal layer or the phase

plate is a difference between two refractive indexes obtained respectively along directions parallel to axes **702** and **703** each of which lies in a plane whose normal is along the path of incident linearly-polarized light

5   and forms an angle of about 45° with respect to a polarization axis **701** of the linearly-polarized light. Therefore, the refractive index anisotropy contributing to the transmissivity in the normal direction is the difference na1-nb1 between the refractive indexes na1 and

10   nb1 as illustrated in Figure **10A**.

The refractive index anisotropy contributing to the change in transmissivity observed when shifting the viewing angle along the long axis of the refractive index

15   ellipse of the liquid crystal molecules and the phase plate is the difference na2-nb2 between the refractive indexes na2 and nb2 as illustrated in Figure **10B**. In such a case, as illustrated in Figure **10B**, the refractive index na2 decreases in proportion to na1 in Figure **10A**.

20   The values nb1 and nb2 are equal to each other (nb1=nb2). Thus, the refractive index anisotropy decreases while inclining the viewing angle along the long axis of the refractive index ellipse.

As illustrated in Figure **10C**, the refractive index anisotropy contributing to the change in transmissivity while shifting the viewing angle along the short axis of the refractive index ellipse is the difference na3-nb3 between the refractive indexes na3 and nb3. Thus, the refractive index anisotropy does not change when shifting the viewing angle along the short axis of the refractive index ellipse.

Finally, a case where the main axis of the refractive index ellipse corresponds to the normal to the display plane of the display device will be discussed. The refractive index contributing to the transmissivity in the normal direction is the difference na4-nb4 between the refractive indexes na4 and nb4 as illustrated in Figure **10D**. Therefore, when using a phase plate having a refractive index ellipse such that na4=nb4, the transmissivity in the normal direction does not change. When the viewing angle is shifted toward an inclined direction, the refractive index contributing to the transmissivity is the difference na5-nb5 between the refractive indexes na5 and nb5 shown in Figure 10E. In such a refractive index ellipse, the refractive index anisotropy increases as the viewing angle is inclined from

the normal direction. Thus, there is provided an effect of compensating for the change in refractive index.

In the above description, the refractive index ellipse of Figure **10D** has been described as a uniaxial refractive index ellipse. Each of the corresponding phase difference compensators **104** and **105** of Figure **4** is a biaxial phase difference compensator which has a refractive index anisotropy also in a plane parallel to the surface of the liquid crystal display device (a large refractive index in the direction indicated by the ar-row **123**). However, the above discussion also applies to this case because the arrow **123** is substantially perpendicular to the polarization axis of the incident linearly-polarized light.

When using a biaxial phase difference compensator, as illustrated in Figure **4**, it is possible to compensate for the polarization axis of linearly-polarized light being incident from an inclined direction and for the rotation of the main axis of the elliptically-polarized light passing through the phase difference compensa-tor **103** in an inclined direction. Therefore, it is possible to obtain better viewing angle characteristics

than that obtained by using a uniaxial phase difference compensator. This will be more apparent from the description of the examples below.

Based on the discussion of the case of a single refractive index ellipse made with reference to Figures **10A-10E**, the effect of phase difference compensation provided by the group of refractive index ellipses illustrated in Figure **9** according to one embodiment of the present invention will be summarized below. Table 1 shows the change (increase/decrease) in the refractive index anisotropy which affects the transmissivity when shifting the viewing angle toward the respective azimuth angles **608** and **609** with linearly-polarized light (polarization direction **607**) being incident upon the group of refractive index ellipses representing the liquid crystal layer and the phase plate in the absence of an applied voltage according to one embodiment of the present invention illustrated in Figure **9**.

TABLE 1

Direction toward which viewing angle is shifted	Change in refractive index anisotropy with respect to normal direction			Compensation effect of group 604, 605 for group 601, 602, 603
	601	602,603	604,605	
608	No change	Decreased	Increased	Yes
609	Decreased	No change	Increased	Yes

It can be seen from Table 1 that the change in viewing angle in an inclined direction can be compensated for by a phase plate having a refractive index ellipse whose refractive index is larger in the normal direction than in a plane parallel to the surface of the liquid crystal display device. Moreover, the refractive index contributing to the transmissivity is a refractive index in the direction at about 45° with respect to the polarization axis of the incident linearly-polarized light. Thus, it is easily understood that the refractive index in this direction is preferably smaller than the refractive index in the direction normal to the surface of the liquid crystal display device.

Production of Liquid Crystal Cell/Orientation Division

A method for producing a liquid crystal cell used in the present example, particularly, a method for the division of the orientation, will be described. The

liquid crystal display device of the present invention can be produced by appropriately combining production methods known in the art.

5   The liquid crystal cell may be produced under conditions that are substantially the same as those for producing a currently-available TN liquid crystal cell on an ordinary TFT (thin film transistor) substrate. According to the present example, however, the rubbing

10   direction (angle) is different from that of the conventional TN liquid crystal cell. Moreover, in order to produce the two divided orientations, UV radiation is performed on an alignment film for controlling the pre-tilt angle.

15

Figure **11A** is a schematic view illustrating a liquid crystal cell of the present example as viewed from the viewer side substrate. Figure **11A** illustrates an arrow **1202** indicating the rubbing direction for the color

20   filter substrate, and another arrow **1203** indicating the rubbing direction for the TFT substrate.

A liquid crystal material is injected into a gap between the substrates which have been rubbed in the

respective rubbing directions described above, and the cell is subjected to a re-alignment treatment. The orientation of the liquid crystal molecules in such a liquid crystal cell will be described. It is believed

5   that the orientation of liquid crystal molecules **1206** across a cross section along X-X' line in Figure **11A**, i.e., a cross section parallel to the rubbing direction, can be schematically represented as in Figure **11B**. The angle between the liquid crystal molecule **1206** and a viewer side

10   substrate **1205** is substantially the same as the angle between the liquid crystal molecule **1206** and a light source side substrate **1204**. Moreover, the liquid crystal molecules substantially in the middle of the liquid crystal cell along the thickness thereof are oriented

15   substantially parallel to the substrate surface. When a voltage is applied across such a liquid crystal layer, a liquid crystal molecule in the intermediate layer may rotate (rise) in the direction indicated by an arrow **1207** or in the direction indicated by an arrow **1208** with the

20   same probability.

According to the present invention, one of the upper or lower substrates is first irradiated with UV light and then subjected to a rubbing process. Figure **11C**

schematically illustrates the orientation of the liquid crystal molecules along the X-X' cross section between such substrates. The UV irradiation process was performed while dividing each pixel into two regions A and B. Only the alignment film on the side of the counter substrate is irradiated with UV light in the region A, whereas only the alignment film on the side of the TFT substrate is irradiated with UV light in the region B. An evaluation of the optical characteristics of the liquid crystal cell which has been processed as described above showed that the liquid crystal molecules in the intermediate layer in the region A rotates in the direction indicated by the arrow **1207**, whereas the liquid crystal molecules in the region B rotates in the direction indicated by the arrow **1208**. In other words, the orientation (pre-tilt angle) of the liquid crystal molecules located in the middle of the liquid crystal layer along the thickness thereof was successfully controlled. Alternatively, the UV irradiation may be performed after the rubbing process. Moreover, the division of the orientation can be realized by means other than the combination of the UV irradiation and the rubbing process.

Example 1

Figure **4** illustrates Example 1 of the present invention. Figure **4** illustrates the liquid crystal cell **101**, the phase plates **102**, **103**, **104** and **105**, and polarizing plates **108** and **109**.

5

Each pixel in the liquid crystal cell **101** is divided into two regions A and B having different orientations. Orientation parameters for the respective regions are as follows.

TABLE 2

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	240nm	0deg	90deg
B	50%	240nm	0deg	270deg

15   Parameters for the polarizing plates are as follows.

TABLE 3

Ref # of polarizing plate	Angle of transmission axis
108	45deg
109	−45deg

Parameters for the phase plates are as follows.

TABLE 4

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
102	120nm	0nm	0deg
103	120nm	0nm	0deg
104	57nm	−72nm	−45deg
105	57nm	−72nm	45deg

5　　　　　Figure **12** illustrates an isocontrast diagram based on values (contrast ratios) obtained by dividing the transmissivity for an applied voltage of 4 V by the transmissivity for an applied voltage of 0 V. The center of the circle corresponds to a viewing angle normal to the display plane (viewing angle 0°), and the concentric

10　circles about the center respectively correspond to various viewing angles of 20°, 40°, 60° and 80°, from the innermost circle. The horizontal axis and the vertical axis represent X_REF and Y_REF, respectively. The iso-

15　contrast curve corresponds to a contrast ratio (CR) of about 50. As is apparent from Figure **12**, the liquid crystal display device of the present example realizes a contrast ratio of about 50 or more in a wide range of viewing angles even over about 60° in any azimuth angle,

20　indicating that the liquid crystal display device has desirable viewing angle characteristics.

Comparative Example 1

　　　　　Comparative Example 1 will be described with

reference to Figure 13. Figure 13 illustrates a liquid crystal cell **6301**, first and second phase difference compensators **6302** and **6303**, and polarizing plates **6305** and **6306**.

5

The liquid crystal cell **6301** is divided into two regions A and B having different orientations. The orientation parameters for the regions are as follows.

TABLE 5

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	240nm	0deg	90deg
B	50%	240nm	0deg	270deg

Parameters for the polarizing plates are as

15   follows.

TABLE 6

Ref # of polarizing plate	Angle of transmission axis
6205	45deg
6206	−45deg

Parameters for the phase plates are as follows.

TABLE 7

Ref # of phase plate	d*(na–nb)	d*(na–nc)	Angle of na axis
6202	120nm	0nm	0deg
6203	120nm	0nm	0deg

5　　　　　Figure 14 illustrates an isocontrast diagram based on values (contrast ratios) obtained by dividing the transmissivity for an applied voltage of 4 V by the transmissivity for an applied voltage of 0 V.　The center of the circle corresponds to a viewing angle normal to 10　the display plane (viewing angle 0°), and the concentric circles about the center respectively correspond to various viewing angles of 20°, 40°, 60° and 80°, from the innermost circle.　The horizontal axis and the vertical axis represent X_REF and Y_REF, respectively.　The iso-15　contrast curve corresponds to a contrast ratio (CR) of about 50.　As is apparent from Figure 14, the liquid crystal display device of Comparative Example 1 has poor viewing angle characteristics in the directions of X_REF and Y_REF.

20

Example 2

　　　　　In this example, various parameter ranges in which the phase difference compensators 104 and 105 function effectively were estimated.　The parameters include the

in-plane retardation d·(na-nb), the retardation along the thickness direction d·(na-nc), and the angle of the na axis. First, preferred ranges for the retardation values of the phase difference compensators d·(na-nb) and d·

5 (na-nc) will be estimated.

Before estimating the parameter ranges, parameters RL and NZ will be defined as follows, with which the parameter ranges can be uniquely determined and compared

10 with the retardation value $(d_{lc} \cdot \Delta n)$ of the liquid crystal layer.

RL=d·(na-nc)/$(d_{lc} \cdot \Delta n)$

NZ=(na-nc)/(na-nb)

15 The influence of the retardation was examined using a liquid crystal display device similar to that of Example 1. It was assumed that the parameters of the phase difference compensators **104** and **105** are equal to each other, and the parameters were varied in the following

20 ranges.

0<|RL|<1 and RL<0

0.1<|NZ|<100 and NZ<0

The effect of each phase difference compensator

was evaluated based on the contrast ratio of the liquid crystal display device at a viewing angle of about 60°. The evaluation parameters ηX_REF and ηY_REF were obtained as ratios of the contrast ratios $CRcompX\_REF$ and

5 $CRcompY\_REF$ (obtained at a viewing angle of 60° in the X_REF and Y_REF directions with phase plate) with respect to the contrast ratio $CRrefX\_REF$ and $CRrefY\_REF$ (obtained at a viewing angle of 60° in the X_REF and Y_REF directions without phase plate as in Comparative Example 1). Thus,

10 $\eta X\_REF = CRcompX\_REF / CRrefX\_REF$; and

$\eta Y\_REF = CRcompY\_REF / CRrefY\_REF$.

Relationship $\eta X\_REF > 1$ or $\eta Y\_REF > 1$ indicates that there is improvement in the contrast ratio provided by the phase difference compensator.

15

Figures **15** and **16** illustrate the results for the ηX_REF and ηY_REF, respectively, while varying the retardation, in which the vertical axis represents $-RL$ and the horizontal axis represents $\log(-NZ)$. Each region

20 in which $\eta X\_REF > 1$ or $\eta Y\_REF > 1$ is hatched in the figures.

As is apparent from Figures **15** and **16**, the region in Figure **15** where $\eta X\_REF > 1$ is larger than the region in Figure **16** where $\eta Y\_REF > 1$. In order to evaluate the effect

of the phase difference compensators **104** and **105** as a whole, a range in which the average value of ηX_REF and ηY_REF is greater than 1 ($\eta X\_REF+\eta Y\_REF/2>1$) was estimated. The results are shown in Figure **17**.

In Figure **17**, the vertical axis represents $-RL$, and the horizontal axis represents $\log(-NZ)$, and the region where $\eta X\_REF+\eta Y\_REF/2>1$ is hatched, while the region where a significant effect is obtained ($\eta X\_REF+\eta Y\_REF/2>10$) is double-hatched.

The above-described results show that the hatched region in Figure **17** is the range of the parameters in which the phase difference compensators **104** and **105** provide a desirable effect.

Particularly, it is practically preferred to use a phase difference compensator whose parameters are in the range above (or on the upper-right side of) a straight line defined through a point which is generally indicated by "A" in Figure **17** ($-RL=0.1$, $\log(-NZ)=-1.0$) and the point "B" ($-RL=0.7$, $\log(-NZ)=-0.2$); in other words, a phase difference compensator whose parameters satisfy $0<|-RL|<1$ and $\log(|-NZ|)>2.0\cdot|-RL|-1.2$, because it is

then possible to extend the margin for variation in characteristics of the phase difference compensator.

In the present example, the effect of the phase difference compensator is evaluated while using a combination of the phase difference compensators **104** and **105** which have the same characteristics (the same parameters). However, it can easily be appreciated that the combination is not limited to the above. For example, assuming that the parameters of the phase difference compensators **104** and **105** are RL_104, NZ_104 and RL_105, NZ_105, respectively, where RLsum=RL_104+RL_105, the range in which the effect of the present invention can be obtained will generally be as follows:

$$0 \leq |RLsum| \leq 2;$$

$$\log(|NZ\_104|) \geq 2.0 \cdot |RL\_104| - 1.2; \text{ and}$$

$$\log(|NZ\_105|) \geq 2.0 \cdot |RL\_105| - 1.2.$$

As shown in Example 1 and Comparative Example 1, sufficiently desirable viewing angle characteristics are obtained in a direction of X_REF±45°, irrespective of the presence/absence of the phase difference compensator. Moreover, desirable viewing angle characteristics have been confirmed for all of the parameters which have been

examined in the present example. Therefore, it is believed that the viewing angle characteristics can be improved as long as the parameters for the phase difference compensators **104** and **105** are within the above-described

5   ranges.

As described above, the liquid crystal display device of the present invention produces a display in a normally black mode (where a black display is produced

10   in the absence of an applied voltage) by applying an electric field substantially vertical to a liquid crystal layer which is made of a nematic liquid crystal material having a positive dielectric anisotropy provided between a pair of polarizing plates which are arranged in a crossed

15   Nicols arrangement. The liquid crystal layer in each pixel region has at least a first domain and a second domain having different orientations, thereby suppressing a change in display quality due to a change in the viewing angle.

20

By providing a phase difference compensator between a liquid crystal cell and a polarizing plate, the refractive index anisotropy of the liquid crystal molecules which are oriented substantially horizontally

to the substrate surface in the absence of an applied voltage is compensated for, thereby realizing a black display with very little viewing angle dependency for any viewing angle including the normal direction. In other words, the refractive index anisotropy of the liquid crystal molecules as viewed from the normal direction can be effectively compensated for by arranging the first and second phase difference compensators each having a positive refractive index anisotropy on the respective sides of the liquid crystal cell so that the phase-delay axes thereof are parallel to the substrate surface and to each other, and perpendicular to the phase-delay axis of the liquid crystal layer. Moreover, by providing a third phase difference compensator having a positive refractive index anisotropy so that the phase-delay axis thereof is parallel to the direction normal to the substrate surface, it is possible to compensate for the change in transmissivity associated with the change in viewing angle, thereby reducing degradation of the black display. Furthermore, by arranging the main axis of the third phase difference compensator along which the in-plane refractive index is maximum to be substantially perpendicular to the polarization axis of the one of the polarizing plates which is closer to the third phase

difference compensator, it is possible to compensate for rotation of the polarization axis of elliptically-polarized light, thereby producing a display with even better viewing angle characteristics.

5

Where the two parameters RL and NZ are defined as follows:

$$RL = d \cdot (na-nc)/(d_{lc} \cdot \Delta n)$$

$$NZ = (na-nc)/(na-nb)$$

10 wherein $(d_{lc} \cdot \Delta n)$ denotes the retardation value of the liquid crystal layer, $(d \cdot (na-nb))$ denotes the in-plane retardation value of the third phase difference compensator, and $(d \cdot (na-nc))$ denotes the retardation along the thickness direction, it is possible to realize

15 a liquid crystal display device with a desirable contrast ratio which has very good viewing angle characteristics in substantially all directions, by appropriately selecting and combining the parameters RL and NZ.

20 The present invention provides a liquid crystal display device of a normally black mode which has a very small change in display quality due to the change in viewing angle. The liquid crystal display device of the present invention does not sacrifice any of the production

efficiency and the transmissivity as in a conventional wide viewing angle liquid crystal display device. The liquid crystal display device of the present invention can be suitably used in various display device 5 applications where a wide viewing angle is required, such as a liquid crystal display device as a computer monitor and a liquid crystal display device for displaying video images.

10 The second part of the present invention will be described below, which comprises Examples 3-16.

First, the principle of operation of the liquid crystal display device according to the present invention 15 will be described with reference to Figure **18**.

Figure **18** schematically illustrates a liquid crystal display device **1800** of the present invention. Figure **18** illustrates a transmission-type liquid crystal 20 display device.

The liquid crystal display device **1800** includes: a liquid crystal layer **101**; a pair of electrodes **100a** and **100b** for applying a voltage across the liquid crystal

layer **101**; a pair of phase plates **102** and **103** provided

on the respective sides of the liquid crystal layer **101**

(the phase plate may of course be of any type, including

a phase difference compensation film, a liquid crystal

5 cell, and the like, as long as it has an appropriate

refractive index anisotropy); another pair of phase

plates **104** and **105** provided on the phase plates **102** and

103, respectively; a further pair of polarizing plates **110**

and **111**; and a pair of polarizing plates **108** and **109**

10 provided in a crossed Nicols arrangement so as to interpose

the above-listed elements therebetween. The polarizing

plates **104**, **105**, **110** and **111** are optional; none, one or

more in any appropriate combination of them may be provided.

Each ellipse in Figure **18** schematically represents a

15 liquid crystal molecules, and each of the arrows represent

an axis of a refractive index ellipse of one of the

polarizing plates (each having a positive uniaxial

characteristic) along which the ellipse has its maximum

refractive index (i.e., the phase-delay axis). The

20 arrows in the polarizing plates **108** and **109** illustrated

in Figure **4** denote the respective polarization axes

(transmission axes) thereof.

Figure **18** illustrates the liquid crystal

layer 101 corresponds to one pixel, and the orientation

of the liquid crystal molecules therein in the absence

of an applied voltage. As the liquid crystal material,

a nematic liquid crystal material having a positive

dielectric anisotropy (or an "Np liquid crystal material")

may be used. The liquid crystal molecules are oriented

substantially parallel to the surfaces of the pair of

substrates (not shown). Electrodes 100a and 100b are

provided on a side of the pair of substrates facing the

liquid crystal layer 101 so as to interpose the liquid

crystal layer 101 therebetween. By applying a voltage

between the electrodes 100a and 100b, an electric field

is applied across the liquid crystal layer 101 in a

direction substantially vertical to the substrate sur-

face.

        As illustrated in Figure 18, the liquid crystal

layer 101 for each axis region includes a first do-

main 101a and a second domain 101b having different

orientations from each other. In the example illustrated

in Figure 18, the director of the liquid crystal molecules

in the first domain 101a and the director of the liquid

crystal molecules in the second domain 101b are oriented

to form an azimuth angle of about 180° with respect to

each other.   The orientation of the liquid crystal molecules is controlled so that when a voltage is applied between the electrodes **100a** and **100b**, the liquid crystal molecules in the first domain **101a** rise in the clockwise direction while those in the second domain **101b** rise in the counterclockwise direction, i.e., the molecules in the different domains rise in opposite directions.   Such an orientation of the directors of the liquid crystal molecules can be achieved by using any orientation control technique known in the art using an alignment film.   When a plurality of such first domains and a plurality of such second domains (in which the director is oriented in a direction different from that in the first domains by about 180°) are provided in each axis region, the viewing angle characteristics can be even more uniform.

Thus, when viewing a gray scale image on the liquid crystal display device **100** with pixels each divided into a plurality of regions having different orientations, the change in the brightness the image experienced while inclining the viewing angle from the normal toward the first domain **101a** is symmetric with that experienced while inclining the viewing angle toward the second domain **101b**. It is preferred that the area of the first domain **101a**

is substantially equal to that of the second domain **101b**.
The areas of respective domains do not have to be equal
to one another for each pixel region, but substantially
the same effect can be obtained when the total area of
the first domains **101a** is substantially equal to the total
area of the second domains **101b** for the entire display
plane. Thus, the way to achieve the division of the
orientation is not limited to that described above.

As illustrated in Figure **18**, the director of the
liquid crystal molecules in the first domain **101a** and the
director of the liquid crystal molecules in the second
domain **101b** are oriented to form an azimuth angle of about
180° with respect to each other. This direction is
parallel to the direction indicted by an arrow **609** in
Figure **18**. Therefore, the refractive index of the liquid
crystal molecules for light incident thereupon in a
direction vertical to the display plane is maximum for
polarized light whose polarization direction is along the
direction **609**, and minimum for polarized light whose
polarization is along the direction **608** which is
perpendicular to the direction **609**. In this specifica-
tion, the direction **609** is assumed to be along the
phase-delay axis of the liquid crystal layer in the absence

of an applied voltage. Generally, the direction of the phase-delay axis of a liquid crystal layer in the absence of an applied voltage is defined as an azimuth angle in which liquid crystal molecules in the middle of the liquid

5   crystal layer along the thickness thereof rise in response to an applied voltage. This definition can be applied not only to a liquid crystal layer in which the liquid crystal molecules are oriented horizontally to the substrate surface (including anti-parallel orientation), but also

10   to a liquid crystal layer in which the liquid crystal molecules are in a twist orientation.

Each of the phase difference compensators **102** and **103** typically has a positive uniaxial refractive index

15   anisotropy, and is arranged so that the phase-delay axis thereof is perpendicular to the phase-delay axis of the liquid crystal layer **101** in the absence of an applied voltage. Therefore, it is possible to control the light leakage due to the refractive index anisotropy of the

20   liquid crystal molecules in the absence of an applied voltage and thus to obtain a desirable black display (or desirable normally black characteristics).

Each of the phase difference compensators **104** and

105 typically has a positive uniaxial refractive index anisotropy, and the phase-delay axis thereof (the direction indicated by the arrow in Figure 18) is arranged to be perpendicular to the substrate surface (i.e.,

5   perpendicular to the phase-delay axis of the liquid crystal layer 101, the phase plate 102 or the phase plate 103) so as to compensate for the change in transmissivity associated with the change in viewing angle. Particularly, light leakage (degradation of the black

10   display) associated with the change in viewing angle in a black display is suppressed. Thus, it is possible to produce a display with even more desirable viewing angle characteristics by providing the phase plates 104 and 105. Alternatively, however, the phase plates 104 and 105 are

15   optional, and none or only one of the phase difference compensators 104 and 105 may be provided.

Each of the phase plates 110 and 111 typically has a positive uniaxial refractive index anisotropy, and the

20   phase-delay axis thereof (the direction indicated by the arrow in Figure 18) is arranged to be perpendicular to the polarization axis of the polarizing plate (i.e., at about 45° with respect to the liquid crystal layer 101, and the polarizing plates 102 and 103) so as to compensate

for the rotation of the polarization axis of ellipti-
cally-polarized light. Thus, it is possible to produce
a display with even more desirable viewing angle
characteristics by providing the phase plates 110 and 111.
5   Alternatively, however, the phase difference compensa-
tors 110 and 111 are optional, and none or only one of
the phase difference compensators 110 and 111 may be
provided.

10   The above-described phase plate does not have to
have a uniaxial refractive index anisotropy, but may
alternatively have a positive biaxial refractive index
anisotropy. A case where a phase plate having a positive
biaxial refractive index anisotropy is used will be
15   described in the other embodiments below.

The elements of the present invention will be
described in greater detail below.

20   Np Liquid Crystal Material: Nematic Liquid Crystal
Material Having Positive Dielectric Anisotropy
As in a liquid crystal display device of a
widely-used TN mode, the present invention employs a
substrate which has been subjected to a horizontal

alignment treatment, and an Np liquid crystal material. Therefore, the time required for a liquid crystal injection process can be reduced to about half of that required in the liquid crystal display device of Japanese 5 Laid-Open Publication No. 7-28068 which employs a substrate which has been subjected to a vertical alignment treatment and an Nn liquid crystal material. Generally, an Np liquid crystal material has a lower viscosity than that of an Nn liquid crystal material, and a substrate 10 which has been subjected to a horizontal alignment treatment has a higher wettability for a liquid crystal material than that of a substrate which has been subjected to a vertical alignment treatment. These factors together provide a multiplier effect of enabling a 15 high-speed liquid crystal injection. The liquid crystal injection process has a significant proportion in the total amount of time required for the production of a liquid crystal display device. Therefore, the substantial reduction in this process leads to a substantial 20 improvement in the production efficiency of the liquid crystal display device.

Vertical Electric Field

    According to the present invention, a pair of

electrodes (at least one of them needs to be transparent) arranged to interpose a liquid crystal layer therebetween are used to apply a vertical (to the substrate) electric field across the liquid crystal layer so as to drive the

5   liquid crystal molecules. Therefore, it is possible to realize an aperture ratio comparable to that of a conventional TN mode liquid crystal display device. Thus, it is not necessary to provide an opaque electrode within the pixel region as in the IPS mode, whereby it is possible

10   to obtain a liquid crystal display device having a larger aperture ratio than a liquid crystal display device of the IPS mode.

Orientation Division

15   Including the TN mode which is currently widely used in the art, a liquid crystal display device in which the transmissivity is varied by moving the liquid crystal molecules in the thickness direction of the liquid crystal layer has a display brightness that is substantially

20   dependent upon the viewing angle (inferior viewing angle characteristics). This will be further described with reference to Figures 5A, 5B and 5C. Figures 5A and 5B schematically illustrate a liquid crystal display device having a liquid crystal layer 203 having a twist

orientation. Referring to Figures **5A** and **5B**, a pair of electrodes **201** and **202** are provided between a pair of polarizing plates **206** and **207** which are arranged in a crossed Nicols arrangement. The liquid crystal layer **203**

5 is interposed between the electrodes **201** and **202**. Figures **5A** and **5B** are drawn so that a liquid crystal molecule in the middle of the liquid crystal layer **203** along the thickness thereof has a long axis along the plane of the figures (such a molecule appears to be the longest).

10 Figures **5A** and **5B** correspond to the absence and the presence of an applied voltage.

As illustrated in Figure **5A**, the liquid crystal molecule **203a** in the middle of the liquid crystal

15 layer **203** along the thickness thereof is oriented substantially parallel to the substrate surface. This state appears to be the same from a viewing angle **204** and from a viewing angle **205**. When a gray scale voltage is applied as in Figure **5B**, different states are viewed from

20 different viewing angles. This is due to the liquid crystal molecules having a positive uniaxial refractive index anisotropy (a cigar-shaped refractive index ellipse). In response to an applied voltage, a liquid crystal molecule **203b** rises in a direction which is

defined by the pre-tilt angle thereof (in the counter-clockwise direction in this example). When the liquid crystal molecule 203b is viewed from the viewing angle 204 (along the long axis of the molecule 203b), the refractive index anisotropy of the cigar-shaped refractive index ellipse disappears (the molecule 203b is viewed to have a circular shape). When the liquid crystal molecule 203b is viewed from the viewing angle 205, the refractive index anisotropy peaks.

Therefore, when the liquid crystal molecules 203b in the liquid crystal cell are viewed from the viewing angle 204, a majority of the molecules are viewed to have a circular shape, i.e., the refractive index anisotropy of the liquid crystal layer decreases. Thus, linearly-polarized light having passed through the polarizing plate 206 reaches the polarizing plate 207 without substantially altered by the liquid crystal layer 203, and then is blocked by the polarizing plate 207 whose polarization axis is perpendicular to that of the polarizing plate 206, thereby reducing the transmissivity. When the liquid crystal molecules 203b in the liquid crystal cell are viewed from the viewing angle 205, a majority of the molecules are viewed to have

an elongated shape, i.e., the refractive index anisotropy of the liquid crystal layer **203** peaks.   Therefore, polarized light having passed through the polarizing plate **206** has the polarization altered by the liquid

5   crystal layer **203** so that the maximum amount of light passes through the polarizing plate **207**.

As a result, the brightness substantially changes while inclining the viewing angle between the direction

10   in which the liquid crystal molecules rise (the viewing angle **204** in Figure **5B**) and the opposite direction (the viewing angle **205** in Figure **5B**), as illustrated in Figure **5C**.   Typically, the viewing angles **204** and **205** are set to correspond to the lower side (the 6 o'clock

15   direction) and the upper side (the 12 o'clock direction) of the panel.   Figure **5C** illustrates various transmissivity curves for various applied voltages. A higher transmissivity in the normal direction corresponds to a higher applied voltage (normally white mode).

20

Thus, in the conventional TN mode, the brightness substantially varies as the viewing angle is inclined along the orientation of the liquid crystal molecules. As can be seen from the above description, such asymmetry

in the gray scale characteristics is seen not only in the TN mode, but also commonly in other various display modes where the liquid crystal molecules are moved along the thickness of the liquid crystal cell, and where

5   orientation division is not employed.

By dividing a pixel into a plurality of regions having different orientations, it is possible to improve the asymmetry in the gray scale characteristics with

10   respect to the viewing angle, and to obtain desirable gray scale characteristics (viewing angle characteristics) which are symmetric in the up-down direction and in the left-right direction. This will be further described with reference to Figures **6A-6E**. For example, each pixel

15   region is divided into two regions (first and second domains) A and B in which the liquid crystal molecules rise in response to an applied voltage in directions different from each other by about 180°, as illustrated in Figures **6A** and **6B**. In the absence of an applied voltage,

20   the liquid crystal molecules in both regions are oriented substantially parallel to the substrate surface, as illustrated in Figure **6A** (the pre-tilt angle is ignored herein for simplicity). When a gray scale voltage is applied, a liquid crystal molecule **303a** in the region A

rise in the counterclockwise direction and a liquid crystal molecule **303b** in the region B rises in the clockwise direction, as illustrated in Figure **6B** (the rising direction is dictated by the pre-tilt angle). As described above, the gray scale characteristics in the regions A and B are dependent upon the viewing angles **304** and **305**, as illustrated in Figures **6C** and **6D**. The regions A and B are present in one pixel region, and therefore the gray scale characteristics of the pixel region as a whole are the average of the respective gray scale characteristics illustrated in Figures **6C** and **6D** with the ratio between the respective areas of the regions A and B being taken into consideration. Thus, by setting the ratio between the area SA of the region A and the area SB of the region B to 1:1, it is possible to obtain gray scale characteristics that are symmetric for the viewing angles **304** and **305**, as illustrated in Figure **6E**.

Next, the ratio SA:SB and the resulting gray scale characteristics will be described so as to estimate a range in which the orientation division effect can be obtained. Figure **7A** illustrates a viewing angle dependency for one of the gray scale characteristics curves in Figure **6E** which is obtained for an applied voltage by which the

transmissivity is about 50% from the normal direction. For the symmetry in the up-down direction, Figure **7B** illustrates the relationship between the ratio TA/TB and the ratio SA/(SA+SB) between the areas SA and SB of the regions A and B. TA and TB denote transmissivities obtained in directions respectively at 50° in the viewing angles **304** (toward the upper side of the panel) and **305** (toward the lower side of the panel) as illustrated in Figures **6A** and **6B**. It can be seen from Figure **7B** that the gray scale characteristics become symmetric in the up-down direction (i.e., TA/TB = about 1) when the ratio SA/(SA+SB) is about 0.5.

The number of divided regions having different orientations is not limited to two, but may be any number as long as the total area of one region having a liquid crystal molecule rising direction and the total area of another region having the opposite liquid crystal molecule rising direction are substantially equal to each other for the entire display plane. In view of the display uniformity, it is preferred that a divided region has a small area, and each pixel region is divided into two or more domains having different orientations. Moreover, each pixel region may have a plurality of regions A and

a plurality of regions B arranged in an alternate manner, as illustrated in Figures **7C** and **7D**. By reducing the size of the unit of orientation division, e.g., by providing a plurality of regions A and a plurality of regions B in

5   each pixel region, the viewing angle characteristics can be even more uniform. This is because the proportion of light passing through both of the regions A and B (indicated by an arrow **401**) with respect to light passing through only one of the regions A and B (indicated by an

10   arrow **402A** or **402B**) increases when the liquid crystal display device is viewed from an inclined direction, as illustrated in Figure **7E**.

Normally Black Mode and Improvement of Contrast Ratio

15   The present invention is in a normally black mode in which a black display is produced in the absence of an applied voltage, and employs a phase difference compensator so as to improve the viewing angle characteristics. The viewing angle characteristics as

20   used herein refer to changes in displayed images observed when inclining the viewing angle from a direction vertical to the display plane of a liquid crystal display device toward an inclined viewing angle. Such viewing angle characteristics (the display characteristics which

change depending upon the viewing angle) include a change in gray scale, a change in contrast ratio, a change in color, and the like. The change in gray scale can be improved by the orientation division as described above.
5   In the following description, the improvement the viewing angle dependency of the contrast ratio provided by the combination of a normally black mode and a phase difference compensator will be described.

10   A contrast ratio (CR) is defined as a value obtained by dividing the maximum transmissivity (the transmissivity in a white display) by the minimum transmissivity (the transmissivity in a black display). In an ordinary liquid crystal display device, the change
15   in transmissivity associated with an inclined viewing angle is greater in a black display than in a white display. Therefore, the change in transmissivity in a black display (also known as "degradation of black display") associated with an inclined viewing angle should be improved in order
20   to improve the viewing angle dependency of the contrast ratio.

This will be described with reference to Figures **8A-8F.** In order to realize a normally black mode,

it is effective to compensate for (cancel out) the refractive index anisotropy of a liquid crystal layer in which the liquid crystal molecules are oriented parallel to the substrate surface in the absence of an applied voltage. The compensation is provided by the phase plates **102** and **103** as illustrated in Figure **4**. In the example illustrated in Figure **8A**, phase plates **502** and **503** provide the same function as that of the phase plates **102** and **103**. As illustrated in Figure **8A**, the liquid crystal layer of the present invention has a substantially horizontal orientation in the absence of an applied voltage. When the liquid crystal layer is viewed from the direction normal to the liquid crystal display device, the maximum refractive index results along a direction (orientation) indicated by an arrow **508** in Figure **8B**, and the minimum refractive index results along a direction perpendicular thereto. In the present invention, the value obtained by multiplying the difference between the maximum and minimum refractive indexes by the thickness of the liquid crystal layer, i.e., the retardation value of the liquid crystal layer, is set to be about 250 nm (about 50 nm to about 500 nm). It is therefore understood that without the phase plates **502** and **503**, the liquid crystal layer **501** interposed

therebetween will transmit light due to the birefringence effect. In view of this, the phase plates **502** and **503** each having a positive uniaxial refractive index anisotropy are used in order to realize the normally black mode characteristics. More specifically, the retardation value of the phase plates **502** and **503** is set to be about 1/2 of that of the liquid crystal layer, i.e., about 125 nm, and the phase-delay axes thereof are aligned with the arrows **509** and **510** (perpendicular to the arrow **508**), respectively. The retardation value of each of the phase plates **502** and **503** is not limited to about 125 nm.

It is only required that the sum of the retardation values of the phase plates **502** and **503** is substantially equal to that of the liquid crystal layer, whereby a black display is produced when viewed from the normal direction in the absence of an applied voltage.

Moreover, it is preferred that the wavelength dependency of the retardation value of the liquid crystal layer is appropriately adjusted with respect to (e.g., substantially equal to) the wavelength dependency of the sum of the retardation values of the phase plates **502** and **503**, thereby obtaining a desirable black display when

viewed from the normal direction in the absence of an applied voltage. Thus, the birefringence effect in the liquid crystal layer can be compensated for by the birefringence effect of the phase plate, thereby obtaining

5   the normally black mode characteristics.

Next, the difference between the phase difference compensation for improving degradation of black display in the normally black mode and that in the normally white

10   mode will be described. In a liquid crystal display device as illustrated in Figure **8A** where a black display is produced in the absence of an applied voltage, the regions A and B in the liquid crystal layer have substantially the same orientations. In the normally

15   white mode, as illustrated in Figure **8D**, where a black display is produced in the presence of an applied voltage, the regions A and B have different orientations. This influences the viewing angle dependency of the retardation value in a black display.

20

Figure **8C** illustrates a change in retardation value for the regions A and B which is observed when shifting the viewing angle between the direction indicated by an arrow **520** and the direction indicated by an arrow **521**

in Figure **8A**. Figure **8G** illustrates a change in retardation value observed when shifting the viewing angle between the direction indicated by an arrow **522** and the direction indicated by an arrow **523** in Figure **8A**. For comparison, Figure **8F** illustrates a change in retardation value observed when shifting the viewing angle between the direction indicated by an arrow **520** and the direction indicated by an arrow **521** (Figure **8E**) in the normally white mode, as illustrated in Figure **8D**; and Figure **8H** illustrates a change in retardation value observed when shifting the viewing angle between the direction indicated by an arrow **522** and the direction indicated by an arrow **523** (Figure **8E**) in the normally white mode, as illustrated in Figure **8D**.

Referring to Figures **8C** and **8G**, the viewing angle dependency of the retardation value in the region A is substantially equal to that in the region B for any of the viewing angles **520**, **521**, **522** and **523**. In addition, the change in retardation is substantially the same for any of the viewing angles **520**, **521**, **522** and **523**. In particular, the limit of the retardation value (the bottom of the curve in Figures **8C** and **8G**) appears at the same degree for any of the viewing angles **520**, **521**, **522** and

523 and in any of the regions (at 0° in the figures). Thus, according to the present invention, it is possible to compensate for the phase difference in a normally black mode using the same phase difference compensator in both

5   of the regions A and B. Moreover, since the limit is at 0°, it is possible to arrange two of the main axes of the refractive index of the phase difference compensator in a plane parallel to the liquid crystal panel, with the other one main axis being arranged to be parallel to the

10   normal to the surface of the liquid crystal panel. The phase difference compensator may be of a uniaxial type. This is due to the fact that the liquid crystal layer has substantially the same orientation in the region A and in the region B in a black display. Moreover, a

15   comparison between Figures 8C and 8G shows that substantially the same change results for any of the viewing angles 520, 521, 522 and 523. This is due to the fact that the liquid crystal molecules are in a horizontal orientation, whereby the phase-delay axis of the liquid

20   crystal layer and the phase-delay axis of each of the phase plates 502 and 503 are in the same plane and are perpendicular to each other. It is thus understood that it is possible to improve the degradation of the black display by compensating for the phase difference by using

the same phase difference compensator for the regions A and B in which one of the main axes of the refractive index is parallel to the normal to the surface of the phase plate, with the other two main axes lying in a plane parallel

5   to the surface of the phase plate.

Referring to Figure **8F**, the changes in retardation value between the directions **520** and **521** for the regions A and B, respectively, are substantially

10   different from each other. For example, the retardation value for the region A takes the minimum value when it is viewed from a direction indicated by the arrow **520**, whereas the retardation value for the region B takes the minimum value when it is viewed from direction indicated

15   by the arrow **521**.

Based on the above, in order to improve the degradation of the black display in the liquid crystal display device, as illustrated in Figure **8A**, it is re-

20   quired to provide different phase difference compensators for the regions A and B, respectively. As the regions A and B are obtained by dividing one pixel region and therefore have very small areas, it is difficult in practice to provide the phase difference compensation for

improving the degradation of black display.

Phase Plate Having Phase-Delay Axis Along Normal to Display Plane

5　　　　The phase plates **104** and **105** illustrated in Figure **18** are provided to compensate for the changes in retardation value for the liquid crystal layer **101**, and the phase plates **102** and **103**, thereby compensating for the degradation of black display. In particular, the

10　phase plates **104** and **105** are provided to compensate for the viewing angle dependency of the retardation value as illustrated in Figures **8C** and **8G**, so that the retardation value is constant (substantially zero) irrespective of the viewing angle. A specific way to achieve this is to

15　employ a liquid crystal cell and a phase plate each having a positive uniaxial refractive index anisotropy, as illustrated in Figure **18**, while using a phase plate having a positive uniaxial refractive index anisotropy in the case of a liquid crystal display device in which the

20　phase-delay axis is included in a plane parallel to the liquid crystal cell in a black display, with the phase-delay axis thereof being parallel to the normal to the surface of the liquid crystal cell.

This will be briefly described with reference to Figure **9**, with particular attention to the angular change in the refractive index anisotropy of the liquid crystal molecules and that of the phase plate. Figure **9** illus-

5   trates a refractive index ellipse **601** of the liquid crystal layer **101**, and refractive index ellipses **602** and **603** of the phase plates **102** and **103**, respectively. Each of the refractive index ellipses has positive uniaxiality, and the optical axis thereof lies in a plane parallel to

10   the surface of the liquid crystal cell.

The change in refractive index observed when viewing a refractive index ellipse **706** (a phase-delay axis **704** and an ellipse **705** perpendicular thereto) will

15   be described with reference to Figures **10A-10E**. First, a case where the liquid crystal display device is viewed from the normal direction will be discussed. The refractive index anisotropy contributing to the birefringence of the liquid crystal layer or the phase

20   plate is a difference between two refractive indexes obtained respectively along directions parallel to axes **702** and **703** each of which lies in a plane whose normal is along the path of incident linearly-polarized light

and forms an angle of about 45° with respect to a polarization axis **701** of the linearly-polarized light. Therefore, the refractive index anisotropy contributing to the transmissivity in the normal direction is the

5 difference na1-nb1 between the refractive indexes na1 and nb1 as illustrated in Figure **10A**.

The refractive index anisotropy contributing to the change in transmissivity observed when shifting the

10 viewing angle along the long axis of the refractive index ellipse of the liquid crystal molecules and the phase plate is the difference na2-nb2 between the refractive indexes na2 and nb2 as illustrated in Figure **10B**. In such a case, as illustrated in Figure **10B**, the refractive

15 index na2 decreases in proportion to na1 in Figure **10A**. The values nb1 and nb2 are equal to each other (nb1=nb2). Thus, the refractive index anisotropy decreases while inclining the viewing angle along the long axis of the refractive index ellipse.

20

As illustrated in Figure **10C**, the refractive index anisotropy contributing to the change in transmissivity while shifting the viewing angle along the short axis of the refractive index ellipse is the

difference na3-nb3 between the refractive indexes na3 and nb3. Thus, the refractive index anisotropy does not change when shifting the viewing angle along the short axis of the refractive index ellipse.

5

Finally, a case where the main axis of the refractive index ellipse corresponds to the normal to the display plane of the display device will be discussed. The refractive index contributing to the transmissivity in the normal direction is the difference na4-nb4 between the refractive indexes na4 and nb4 as illustrated in Figure **10D**. Therefore, when using a phase plate having a refractive index ellipse such that na4=nb4, the transmissivity in the normal direction does not change. When the viewing angle is shifted toward an inclined direction, the refractive index contributing to the transmissivity is the difference na5-nb5 between the refractive indexes na5 and nb5. In such a refractive index ellipse, the refractive index anisotropy increases as the viewing angle is inclined from the normal direction. Thus, there is provided an effect of compensating for the change in refractive index.

Based on the discussion of the case of a single

refractive index ellipse made with reference to Figures **10A-10E,** the effect of phase difference compensation provided by the group of refractive index ellipses illustrated in Figure **9** according to one embodiment of

5   the present invention will be summarized below. Table 8 shows the change (increase/decrease) in the refractive index anisotropy which affects the transmissivity when shifting the viewing angle toward the respective azimuth angles **608** and **609** with linearly-polarized light

10   (polarization direction **607**) being incident upon the group of refractive index ellipses representing the liquid crystal layer and the phase plate in the absence of an applied voltage according to one embodiment of the present invention illustrated in Figure **9.**

TABLE 8

Direction toward which viewing angle is shifted	Change in refractive index anisotropy with respect to normal direction			Compensation effect of group 604, 605 for group 601, 602, 603
	601	602,603	604,605	
608	No change	Decreased	Increased	Yes
609	Decreased	No change	Increased	Yes

It can be seen from Table 8 that the change in viewing angle in an inclined direction can be compensated for by a phase plate having a refractive index ellipse

whose refractive index is maximum in the direction normal to the surface of the liquid crystal display device. Moreover, the refractive index contributing to the transmissivity is a refractive index in the direction at about 45° with respect to the polarization axis of the incident linearly-polarized light. Thus, it is easily understood that the refractive index in this direction is preferably smaller than the refractive index in the direction normal to the surface of the liquid crystal display device.

Phase Plate Having Phase-Delay Axis at 45° With Respect to Phase-Delay Axis of Liquid Crystal Layer

The phase plates 110 and 111 illustrated in Figure 18 rotate the main axis of elliptically-polarized light (including linearly-polarized light) incident thereupon.

For improving the contrast ratio, it is necessary to suppress the increase in transmissivity (degradation of the black display) in a black display as viewed from an inclined direction. In other words, polarized light being incident upon the polarizing plate 109 from any direction needs to be linearly-polarized light whose

polarization axis is perpendicular to the polarization axis (transmission axis) of the polarizing plate **109**, or elliptically-polarized light whose ellipticity is substantially zero and whose main axis is perpendicular to

5   the polarization axis of the polarizing plate **109**. The change in retardation of the liquid crystal layer **101** associated with the change in viewing angle is compensated for by the above-described phase plates **104** and **105**. The compensation for the change in retardation primarily

10   corresponds to suppression of the increase in ellipticity of elliptically-polarized light (i.e., suppressing the increase to substantially zero). Moreover, in order to obtain a desirable contrast, it is necessary to compensate for the rotation of the main axis of elliptically-

15   polarized light associated with a change in viewing angle. The phase plates **110** and **111** compensate for the rotation of the main axis of elliptically-polarized light.

Figure **19** illustrates the relationship between

20   the transmissivity in a black display and the retardation value of the phase plates **110** and **111**, where the viewing angle is set to about 60° in an azimuth angle parallel to the long axis of a liquid crystal molecule (the direction indicated by the arrow **609**). As is apparent

from Figure 19, a desirable black display can be obtained by appropriately setting the retardation value of the phase plates 110 and 111, and adjusting the rotation angle of the main axis of elliptically-polarized light. Only one of the phase plates 110 and 111 may be used, alternatively.

Definitions for parameters characterizing a liquid crystal layer, a polarizing plate and a phase plate used commonly in the following examples will be described.

Each of the parameters, particularly angles, are defined based on an XYZ rectangular coordinate system which is appropriately assumed on a liquid crystal panel. As illustrated in Figures 1A-1C, the reference coordinate system only needs to have the XY plane thereof being parallel to the liquid crystal panel, and the direction of the X and Y axes is not limited to any particular direction (e.g., it may be any of those illustrated in Figures 1A-1C). Note, however, that for any particular liquid crystal display device, a set of axes is assumed commonly for the liquid crystal layer, the polarizing plate, and the phase plate thereof. In the following description, the main axes of the reference coordinate

system are denoted by "X_REF", "Y_REF", and "Z_REF", respectively.

The parameters characterizing the orientation of
5 the liquid crystal molecules in the liquid crystal layer will be described with reference to Figures **2A-2D**. Figure **2A** is a perspective view illustrating a liquid crystal cell. For the sake of simplicity, a single domain across which orientation of liquid crystal molecules is
10 uniform will be described below. Where a pixel region is divided into a plurality of domains having different orientations, parameters characterizing the liquid crystal layer for each domain include: ① the retardation value of the liquid crystal layer; ② the twist angle of
15 the liquid crystal layer; and ③ the orientation of the liquid crystal molecules (those located in the middle of the liquid crystal layer along the thickness thereof) (i.e., the phase-delay axis of the liquid crystal layer).

20 Figure **2B** is a cross-sectional view illustrating a liquid crystal layer. The retardation value of the liquid crystal layer is defined as a product $d \cdot \Delta n$ of the refractive index anisotropy Δn of a liquid crystal material **5103** of the liquid crystal layer interposed

between substrates **5101** and **5102** and the distance d of

the substrate **5101** (e.g., a substrate on which a color

filter is provided) and the substrate **5102** (e.g., a

substrate on which a TFT array is provided) (the distance

5   d_{lc} corresponds to the thickness of the liquid crystal

layer = the cell gap).

Figure **2C** is a plan view of the liquid crystal cell

as viewed from the viewer side. A line **5104** is parallel

10   to the long axis of a liquid crystal molecule adjacent

to the light source side substrate **5102**, and a line **5105**

is parallel to the long axis of another liquid crystal

molecule adjacent to the viewer side substrate **5101**. For

the sake of simplicity, it is assumed in the following

15   description that the twist angle of the liquid crystal

molecules is about 90° or less. Herein, the twist angle

of the liquid crystal layer is defined as an angle obtained

by rotating the line **5104** to meet the line **5105**, wherein

a positive twist angle is obtained by rotating the

20   line **5104** counterclockwise. The angle as defined above

is denoted by "θ_{twist}" in the figure.

The orientation of the liquid crystal layer is

defined as follows. Referring again to Figure **2C**, a

line **5106** is shown to equiangularly bisect the angle θ_{twist}.
The line **5106** represents a direction in which a liquid
crystal molecule located in the middle of the liquid
crystal layer along the thickness thereof rises in re-
sponse to an applied electric field. This direction is
called the orientation or phase-delay axis of the liquid
crystal layer. Herein, only some of the liquid crystal
molecules present in the liquid crystal layer will be
considered, whose long axes are substantially parallel
to the line **5106** in the presence of a voltage which gives
the liquid crystal layer an intermediate transmissivity
(a gray scale voltage). Figure **2D** is a cross-sectional
view of the liquid crystal cell along the line **5106**.
Figure **2C** further shows an arrow **5107** parallel to the
line **5106**. The tip of the arrow **5107** corresponds to a
rising tip (end) of a liquid crystal molecule. Then, the
orientation of the liquid crystal layer is defined as an
angle β between the arrow **5107** and the reference axis
X_REF, wherein a positive orientation is obtained by
rotating the reference axis X_REF counterclockwise.

A parameter for a polarizing plate is a direction
(angle) of the polarization axis (transmission axis)
thereof. Definition of the direction of the polarization

axis will be described (not shown in the figures). The direction of the polarization axis is defined as an angle between the polarization axis and the reference axis X_REF, wherein a positive direction is obtained by rotating the reference axis X_REF counterclockwise. Of course, polarization axis directions α, $\alpha+180°$, and $\alpha-180°$ all denote an equivalent polarizing plate.

Parameters for a phase plate are defined as follows. Parameters for a phase plate include: ① the in-plane retardation value (in a plane parallel to the display plane); ② the retardation value along the thickness direction (in a direction vertical to the liquid crystal display plane); and ③ the angle of the axis a (the angle between X_REF and the axis a).

Figures **3A** and **3B** show a refractive index ellipse of the phase plate. The three main axes of the refractive index ellipse of the phase plate used in the examples of the present invention are denoted by a, b and c, respectively. The main axes a, b and c together form a rectangular coordinate system. The main axes a and b lie in a plane parallel to the phase plate surface, i.e., in a plane parallel to the display plane. The refractive

index values along the main axes a, b and c are denoted by na, nb and nc, respectively. The thickness of the phase plate is denoted by d. Then,

① The in-plane retardation of the phase plate is
5   defined as d·(na-nb);

② The retardation along the thickness direction is defined as d·(na-nc); and

③ The angle of the main axis a is defined as an angle γ between the reference axis X_REF and the main
10   axis a, wherein a positive angle is obtained by rotating the reference axis X_REF counterclockwise.

Production of Liquid Crystal Cell/Orientation Division

A method for producing a liquid crystal cell,
15   particularly, a method for the orientation division, will be described below. The liquid crystal display device of the present invention can be produced by appropriately combining production methods known in the art.

20   The liquid crystal cell may be produced under conditions that are substantially the same as those for producing a currently-available TN liquid crystal cell on an ordinary TFT (thin film transistor) substrate. According to the present example, however, the rubbing

direction (angle) is different from that of the conventional TN liquid crystal cell. Moreover, in order to produce the two divided orientations, UV radiation is performed on an alignment film for controlling the pre-tilt angle.

Figure **11A** is a schematic view illustrating a liquid crystal cell of the present example as viewed from the viewer side substrate. Figure **11A** illustrates an arrow **1202** indicating the rubbing direction for the color filter substrate, and another arrow **1202** indicating the rubbing direction for the TFT substrate.

A liquid crystal material is injected into a gap between the substrates which have been rubbed in the respective rubbing directions described above, and the cell is subjected to a re-alignment treatment. The orientation of the liquid crystal molecules in such a liquid crystal cell will be described. It is believed that the orientation of liquid crystal molecules **1206** across a cross section along the X-X' line in Figure **11A**, i.e., a cross section parallel to the rubbing direction, can be schematically represented as in Figure **11B**. The angle between the liquid crystal molecule **1206** and a

viewer side substrate **1205** is substantially the same as the angle between the liquid crystal molecule **1206** and a light source side substrate **1204**. Moreover, the liquid crystal molecules substantially in the middle of the

5   liquid crystal cell along the thickness thereof are oriented substantially parallel to the substrate surface. When a voltage is applied across such a liquid crystal layer, a liquid crystal molecule in the intermediate layer may rotate (rise) in the direction indicated by an ar-

10   row **1207** or in the direction indicated by an arrow **1208** with the same probability.

According to the present invention, one of the upper or lower substrates is first irradiated with UV light

15   and then subjected to a rubbing process. Figure **11C** schematically illustrates the orientation of the liquid crystal molecules along the X-X' cross section between such substrates.

20   The UV irradiation process was performed while dividing each pixel into two regions A and B. Only the alignment film on the side of the counter substrate is irradiated with UV light in the region A, whereas only the alignment film on the side of the TFT substrate is

irradiated with UV light in the region B. An evaluation of the optical characteristics of the liquid crystal cell which has been processed as described above showed that the liquid crystal molecules in the intermediate layer in the region A rotates in the direction indicated by the arrow **1207**, whereas the liquid crystal molecules in the region B rotates in the direction indicated by the arrow **1208**. In other words, the orientation (pre-tilt angle) of the liquid crystal molecules located in the middle of the liquid crystal layer along the thickness thereof was successfully controlled. Alternatively, the UV irradiation may be performed after the rubbing process. Moreover, the orientation division can be realized by means other than the combination of the UV irradiation and the rubbing process.

Moreover, it is preferred to use light-blocking beads as spacer beads.

This is because, in the present invention, normally black mode characteristics are obtained by compensating for the retardation of the liquid crystal layer with a phase plate, i.e., if the retardation value of a portion the liquid crystal layer changes due to the

beads, or the like, present therein, a black display cannot be obtained in the portion, thereby reducing the contrast. Thus, such a portion of the liquid crystal layer should be blocked from light (e.g., by using light-blocking

5   beads) or such a portion should not be provided at all (e.g., by providing a bead-less liquid crystal display device).

Example 3

10   A liquid crystal display device **1800** according to Example 3 of the present invention will be schematically illustrated with reference to Figure **18**. Figure **18** illustrates a liquid crystal cell **101**, phase plates **102**, **103**, **104**, **105**, **110** and **111**, and polarizing plates **108** and

15   **109**.

The liquid crystal cell **101** in each pixel is divided into two regions A and B having different orientations. The orientation parameters for the regions

20   are as follows.

TABLE 9

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	261nm	0deg	90deg
B	50%	261nm	0deg	270deg

Parameters for the polarizing plates are as follows.

TABLE 10

Ref # of polarizing plate	Angle of transmission axis
108	45deg
109	−45deg

Parameters for the phase plates are as follows.

TABLE 11

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
102	130nm	0nm	0deg
103	130nm	0nm	0deg
104	0nm	−131nm	0deg
105	0nm	−131nm	0deg
110	29nm	0nm	−45deg
111	29nm	0nm	45deg

Figure **20** illustrates the relationship between the transmissivity and the applied voltage in the liquid crystal display device of the present example. In Figure **20**, a transmissivity of 100% corresponds to the transmissivity for an applied voltage of about 4 V. It can be seen from Figure **20** that the liquid crystal display device of the present example produces a black display

at an applied voltage of 0 V, and the transmissivity increases (toward a white display) as the applied voltage increases.

5   Each of Figures **21A-21C** illustrates the viewing angle (polar angle: an angle with respect to the normal to the display plane) dependency of the transmissivity for various gray scale levels in an 8-gray-scale-level display. The viewing angle is shifted along a direction

10   parallel to the X_REF axis in Figure **21A**, along a direction parallel to the X_REF±45° axis in Figure **21B**, and along a direction parallel to the Y_REF axis in Figure **21C**. It can be seen from the figures that the gray scale characteristics of the liquid crystal display device of

15   the present example are substantially symmetric.

          Figure **22** illustrates an isocontrast diagram based on values (contrast ratios) obtained by dividing the transmissivity for an applied voltage of 4 V by the

20   transmissivity for an applied voltage of 0 V. The center of the circle corresponds to a viewing angle normal to the display plane (viewing angle 0°), and the concentric circles about the center respectively correspond to various viewing angles of 20°, 40°, 60° and 80°, from the

innermost circle. The horizontal axis and the vertical axis represent X_REF and Y_REF, respectively. The innermost, intermediate and outermost isocontrast curves correspond to contrast ratios (CRs) of about 100, 50 and

5   20, respectively. As is apparent from Figure **22**, the liquid crystal display device of the present example realizes a contrast ratio of about 50 or more in a wide range of viewing angles even over about 60° in any azimuth angle, indicating that the liquid crystal display device

10   has desirable viewing angle characteristics.

Example 4

Figure **23** schematically illustrates the struc-ture of a liquid crystal display device according to

15   Example 4 of the present invention. Figure **23** illus-trates a liquid crystal cell **6101**, phase plates **6102**, **6103**, **6104** and **6105**, and polarizing plates **6106** and **6107**.

The liquid crystal cell **6101** in each pixel is

20   divided into two regions A and B having different orientations. The orientation parameters for the regions are as follows.

TABLE 12

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	261nm	0deg	90deg
B	50%	261nm	0deg	270deg

Parameters for the polarizing plates are as follows.

TABLE 13

Ref # of polarizing plate	Angle of transmission axis
6106	45deg
6107	−45deg

Parameters for the phase plates are as follows.

TABLE 14

Ref # of phase plate	$d*(na-nb)$	$d*(na-nc)$	Angle of na axis
6102	130nm	0nm	90deg
6103	130nm	0nm	90deg
6104	36nm	0nm	−45deg
6105	0nm	−263nm	90deg

As in Example 3, the liquid crystal display device of the present example has very good viewing angle characteristics.

Example 5

Figure **24** schematically illustrates the structure of a liquid crystal display device according to Example 5 of the present invention. Figure **24** illustrates a liquid crystal cell **6201**, phase plates **6202, 6203, 6204** and **6205**, and polarizing plates **6206** and **6207**.

The liquid crystal cell **6201** in each pixel is divided into two regions A and B having different orientations. The orientation parameters for the regions are as follows.

TABLE 15

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	261nm	0deg	90deg
B	50%	261nm	0deg	270deg

Parameters for the polarizing plates are as follows.

TABLE 16

Ref # of polarizing plate	Angle of transmission axis
6206	45deg
6207	−45deg

Parameters for the phase plates are as follows.

TABLE 17

Ref # of phase plate	d*(na-nb)	d*(na-nc)	Angle of na axis
6202	130nm	0nm	0deg
6203	130nm	0nm	0deg
6204	50nm	−96nm	−45deg
6205	50nm	−96nm	45deg

As in Example 3, the liquid crystal display device of the present example has very good viewing angle characteristics.

10

Example 6

Figure 25 schematically illustrates the struc-ture of a liquid crystal display device according to Example 6 of the present invention. Figure 25 illus-

15   trates a liquid crystal cell 6301, phase plates 6302, 6303 and 6304, and polarizing plates 6305 and 6306.

The liquid crystal cell 6301 in each pixel is divided into two regions A and B having different

20   orientations. The orientation parameters for the regions are as follows.

TABLE 18

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	261nm	0deg	90deg
B	50%	261nm	0deg	270deg

5   Parameters for the polarizing plates are as

follows.

TABLE 19

Ref # of polarizing plate	Angle of transmission axis
6305	45deg
6306	−45deg

Parameters for the phase plates are as follows.

TABLE 20

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
6302	130nm	0nm	90deg
6303	130nm	0nm	90deg
6304	62nm	−193nm	−45deg

As in Example 3, the liquid crystal display device

20   of the present example has very good viewing angle

characteristics.

Example 7

Figure 26 schematically illustrates the struc-

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ture of a liquid crystal display device according to Example 7 of the present invention. Figure **26** illustrates a liquid crystal cell **6401**, phase plates **6402**, **6403**, **6404** and **6405** and polarizing plates **6406** and **6407**.

5

The liquid crystal cell **6401** in each pixel is divided into two regions A and B having different orientations. The orientation parameters for the regions are as follows.

TABLE 21

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	261nm	0deg	90deg
B	50%	261nm	0deg	270deg

15 Parameters for the polarizing plates are as follows.

TABLE 22

Ref # of polarizing plate	Angle of transmission axis
6406	45deg
6407	−45deg

Parameters for the phase plates are as follows.

TABLE 23

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
6402	130nm	0nm	0deg
6403	130nm	0nm	0deg
6404	36nm	0nm	45deg
6405	0nm	−263nm	0deg

As in Example 3, the liquid crystal display device of the present example has very good viewing angle characteristics.

10   Example 8

Figure **30** schematically illustrates the structure of a liquid crystal display device according to Example 8 of the present invention. Figure **30** illustrates a liquid crystal cell **6501**, phase plates **6502**, **6503**

15   and **6504** and polarizing plates **6505** and **6506**.

The liquid crystal cell **6501** in each pixel is divided into two regions A and B having different orientations. The orientation parameters for the regions

20   are as follows.

TABLE 24

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	261nm	0deg	90deg
B	50%	261nm	0deg	270deg

Parameters for the polarizing plates are as follows.

TABLE 25

Ref # of polarizing plate	Angle of transmission axis
6505	45deg
6506	−45deg

Parameters for the phase plates are as follows.

TABLE 26

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
6502	130nm	0nm	0deg
6503	130nm	0nm	0deg
6504	62nm	−193nm	45deg

In all of Examples 3-8, the twist angle of the liquid crystal layer is 0°, though the effective twist angle of the present invention is not limited to this angle. By providing the liquid crystal layer with any appropriate twist angle, the ranges, the margins, and the like, of the respective parameters may be extended. Particularly,

in a range where the twist angle is 0° or greater and less than 90°, the orientation division can easily be achieved without having to mix a chiral agent in the liquid crystal material. An example with a twist angle of about 30° will

5   be described below.

Example 9

Figure 18 schematically illustrates the structure of a liquid crystal display device according to

10   Example 9 of the present invention. Figure 18 illustrates a liquid crystal cell 101, phase plates 102, 103, 104, 105, 110 and 111, and polarizing plates 108 and 109.

The liquid crystal cell 101 in each pixel is

15   divided into two regions A and B having different orientations. The orientation parameters for the regions are as follows.

TABLE 27

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	303nm	−30deg	90deg
B	50%	303nm	−30deg	270deg

Parameters for the polarizing plates are as follows.

TABLE 28

Ref # of polarizing plate	Angle of transmission axis
108	45deg
109	−45deg

Parameters for the phase plates are as follows.

TABLE 29

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
102	154nm	0nm	9.4deg
103	154nm	0nm	−9.4deg
104	0nm	−150nm	0deg
105	0nm	−150nm	0deg
110	48nm	0nm	−45deg
111	48nm	0nm	45deg

Figure **27** illustrates the relationship between the transmissivity and the applied voltage in the liquid crystal display device of the present example. In Figure **27**, a transmissivity of 100% corresponds to the transmissivity for an applied voltage of about 4 V. It can be seen from Figure **27** that the liquid crystal display device of the present example produces a black display at an applied voltage of 0 V, and the transmissivity increases (toward a white display) as the applied voltage increases.

Each of Figures **28A**-**28C** illustrates the viewing

angle (polar angle: an angle with respect to the normal

to the display plane) dependency of the transmissivity

5   for various gray scale levels in an 8-gray-scale-level

display. The viewing angle is shifted along a direction

parallel to the X_REF axis in Figure **28A**, along a direction

parallel to the X_REF±45° axis in Figure **28B**, and along

a direction parallel to the Y_REF axis in Figure **28C**. It

10   can be seen from the figures that the gray scale

characteristics of the liquid crystal display device of

the present example are substantially symmetric.

Figure **29** illustrates an isocontrast diagram

15   based on values (contrast ratios) obtained by dividing

the transmissivity for an applied voltage of 4 V by the

transmissivity for an applied voltage of 0 V. The center

of the circle corresponds to a viewing angle normal to

the display plane (viewing angle 0°), and the concentric

20   circles about the center respectively correspond to

various viewing angles of 20°, 40°, 60° and 80°, from the

innermost circle. The horizontal axis and the vertical

axis represent X_REF and Y_REF, respectively. The

innermost, intermediate and outermost isocontrast curves

correspond to contrast ratios (CRs) of about 100, 50 and 20, respectively. As is apparent from Figure **29**, the liquid crystal display device of the present example realizes a contrast ratio of about 10 or more in a wide range of viewing angles even over about 60° in any azimuth angle, indicating that the liquid crystal display device has desirable viewing angle characteristics.

Example 10

Figure **23** schematically illustrates the structure of a liquid crystal display device according to Example 10 of the present invention. Figure **23** illustrates a liquid crystal cell **6101**, phase plates **6102, 6103, 6104** and **6105**, and polarizing plates **6106** and **6107**.

The liquid crystal cell **6101** in each pixel is divided into two regions A and B having different orientations. The orientation parameters for the regions are as follows.

TABLE 30

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	303nm	−30deg	90deg
B	50%	303nm	−30deg	270deg

Parameters for the polarizing plates are as follows.

TABLE 31

Ref # of polarizing plate	Angle of transmission axis
6106	45deg
6107	−45deg

Parameters for the phase plates are as follows.

TABLE 32

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
6102	154nm	0nm	9.4deg
6103	154nm	0nm	−9.4deg
6104	58nm	0nm	−45deg
6105	0nm	−317nm	90deg

As in Example 9, the liquid crystal display device of the present example has very good viewing angle characteristics.

Example 11

Figure **24** schematically illustrates the structure of a liquid crystal display device according to Example 11 of the present invention. Figure **24** illustrates a liquid crystal cell **6201**, phase plates **6202, 6203,**

6204 and 6205, and polarizing plates 6206 and 6207.

The liquid crystal cell 6201 in each pixel is divided into two regions A and B having different orientations. The orientation parameters for the regions are as follows.

TABLE 33

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	303nm	30deg	90deg
B	50%	303nm	30deg	270deg

Parameters for the polarizing plates are as follows.

TABLE 34

Ref # of polarizing plate	Angle of transmission axis
6206	45deg
6207	−45deg

Parameters for the phase plates are as follows.

TABLE 35

Ref # of phase plate	d*(nα-nb)	d*(nα-nc)	Angle of nα axis
6202	154nm	0nm	9.4deg
6203	154nm	0nm	−9.4deg
6204	95nm	−123nm	−45deg
6205	95nm	−123nm	45deg

As in Example 9, the liquid crystal display device of the present example has very good viewing angle characteristics.

10

Example 12

Figure 25 schematically illustrates the structure of a liquid crystal display device according to Example 12 of the present invention. Figure 25 illus-

15 trates a liquid crystal cell **6301**, phase plates **6302, 6303** and **6304**, and polarizing plates **6305** and **6306**.

The liquid crystal cell **6301** in each pixel is divided into two regions A and B having different

20 orientations. The orientation parameters for the regions are as follows.

TABLE 36

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	303nm	−30deg	90deg
B	50%	303nm	−30deg	270deg

5   Parameters for the polarizing plates are as follows.

TABLE 37

Ref # of polarizing plate	Angle of transmission axis
6305	45deg
6306	−45deg

Parameters for the phase plates are as follows.

TABLE 38

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
6302	154nm	0nm	9.4deg
6303	154nm	0nm	−9.4deg
6304	113nm	−260nm	−45deg

As in Example 9, the liquid crystal display device

20   of the present example has very good viewing angle characteristics.

Example 13

Figure 26 schematically illustrates the struc-

ture of a liquid crystal display device according to Example 13 of the present invention. Figure **26** illustrates a liquid crystal cell **6401**, phase plates **6402, 6403, 6404** and **6405**, and polarizing plates **6406** and **6407**.

The liquid crystal cell **6401** in each pixel is divided into two regions A and B having different orientations. The orientation parameters for the regions are as follows.

TABLE 39

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	303nm	−30deg	90deg
B	50%	303nm	−30deg	270deg

Parameters for the polarizing plates are as follows.

TABLE 40

Ref # of polarizing plate	Angle of transmission axis
6406	45deg
6407	−45deg

Parameters for the phase plates are as follows.

TABLE 41

Ref # of phase plate	d*(na-nb)	d*(na-nc)	Angle of na axis
6402	154nm	0nm	9.4deg
6403	154nm	0nm	−9.4deg
6404	58nm	0nm	45deg
6405	0nm	−317nm	0deg

As in Example 9, the liquid crystal display device of the present example has very good viewing angle characteristics.

10   Example 14

Figure 30 schematically illustrates the structure of a liquid crystal display device according to Example 14 of the present invention. Figure 30 illustrates a liquid crystal cell **6501**, phase plates **6502, 6503**

15   and **6504**, and polarizing plates **6505** and **6506**.

The liquid crystal cell **6501** in each pixel is divided into two regions A and B having different orientations. The orientation parameters for the regions

20   are as follows.

TABLE 42

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	303nm	−30deg	90deg
B	50%	303nm	−30deg	270deg

Parameters for the polarizing plates are as
follows.

TABLE 43

Ref # of polarizing plate	Angle of transmission axis
6505	45deg
6506	−45deg

Parameters for the phase plates are as follows.

TABLE 44

Ref # of phase plate	$d*(n_a-n_b)$	$d*(n_a-n_c)$	Angle of n_a axis
6502	154nm	0nm	9.4deg
6503	154nm	0nm	−9.4deg
6504	113nm	−260nm	45deg

As in Example 9, the liquid crystal display device
of the present example has very good viewing angle
characteristics.

Example 15

Example 5 employs the phase plates **6204** and **6205**
so as to compensate for the degradation of black display
due to a change in retardation of the liquid crystal
layer **6201**, the phase plate **6202** and **6203** associated with

an inclined viewing angle. The polarizing plate used in
the present invention may be provided with a protective
film made of a material such as TAC on a surface thereof.
When TAC, or the like, having a refractive index anisotropy
is used as a material protecting the polarizing plate,
it may be necessary to consider the refractive index
anisotropy of TAC when designing the optical system for
suppressing the degradation of black display associated
with an inclined viewing angle. The viewing angle
characteristics can be improved by appropriately
selecting the retardation values for the phase plates **6204**
and **6205** to compensate for the degradation of black display,
while considering the change in retardation value of TAC
as well as the change in retardation values of the phase
plates **6202** and **6203**. In this and following examples, TAC
is employed and considered as an independent phase
difference compensator (phase plate).

The present example will be described with
reference to Figure **31**. Figure **31** illustrates a liquid
crystal cell **2401**, phase plates **2402**, **2403**, **2404** and **2405**,
and polarizing plates **2408** and **2409**. Figure **31** also
illustrates TACs **2406** and **2407** provided for the purpose
of protecting the polarizing plates. Since TAC has a

refractive index anisotropy, each TAC between a polarizing plate and the liquid crystal cell is shown in Figure **31** to be an independent phase plate.

5   The liquid crystal cell **2401** is divided into two regions A and B having different orientations. The orientation parameters for the regions are as follows.

TABLE 45

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	260nm	0deg	90deg
B	50%	260nm	0deg	270deg

Parameters for the polarizing plates are as follows.

TABLE 46

Ref # of polarizing plate	Angle of transmission axis
2408	45deg
2409	−45deg

20   Parameters for the phase plates are as follows.

TABLE 47

Ref # of phase plate	d*(na-nb)	d*(na-nc)	Angle of na axis
2402	130nm	0nm	0deg
2403	130nm	0nm	0deg
2404	92nm	−92nm	−45deg
2405	92nm	−92nm	45deg
2406	5nm	50nm	−45deg
2407	5nm	50nm	45deg

Figure **32** illustrates the relationship between the transmissivity and the applied voltage in the liquid crystal display device of the present example. In Figure **32**, a transmissivity of 100% corresponds to the transmissivity for an applied voltage of about 4 V. It can be seen from Figure **32** that the liquid crystal display device of the present example produces a black display at an applied voltage of 0 V, and the transmissivity increases (toward a white display) as the applied voltage increases.

Each of Figures **33-36** illustrates the viewing angle (polar angle: an angle with respect to the normal to the display plane) dependency of the transmissivity for various gray scale levels in an 8-gray-scale-level display. The viewing angle is shifted along a direction parallel to the X_REF axis in Figure **33**, along a direction

parallel to the X_REF+45° axis in Figure **34**, along a direction parallel to the X_REF-45° axis in Figure **35**, and along a direction parallel to the Y_REF axis in Figure **36**. It can be seen from the figures that the gray

5　scale characteristics of the liquid crystal display device of the present example are substantially symmetric.

Figure **37** illustrates an isocontrast diagram based on values (contrast ratios) obtained by dividing

10　the transmissivity for an applied voltage of 4 V by the transmissivity for an applied voltage of 0 V. The center of the circle corresponds to a viewing angle normal to the display plane (viewing angle 0°), and the concentric circles about the center respectively correspond to

15　various viewing angles of 20°, 40°, 60° and 80°, from the innermost circle. The horizontal axis and the vertical axis represent X_REF and Y_REF, respectively. The iso-contrast curve corresponds to a contrast ratio (CR) of about 50. As is apparent from Figure **37**, the liquid

20　crystal display device of the present example realizes a contrast ratio of about 50 or more in a wide range of viewing angles even over about 60° in any azimuth angle, indicating that the liquid crystal display device has desirable viewing angle characteristics.

Although Example 15 is based on the various conditions shown in Tables 45-47, the effective conditions of the present invention are not limited to these conditions. In particular, the above-described effects can be obtained as long as the liquid crystal display device has a liquid crystal layer in which the liquid crystal molecules are in a substantially horizontal orientation in the absence of an applied voltage and which exhibits at least two different orientations in the presence of an applied voltage, while the liquid crystal display device employs a phase difference compensator which is designed to compensate for the refractive index anisotropy exhibited by the liquid crystal layer in the absence of an applied voltage substantially in any direction.

For example, it is possible to appropriately select the most suitable phase plate for any of various retardation values of a liquid crystal layer in a liquid crystal display device having a structure as illustrated in Figure 31. Such a selection for the phase plates will be described with reference to Figures 38-40. In Figure 38, the horizontal axis RLC represents a retardation

value of the liquid crystal layer (see Table 45), the vertical axis R1 represents the retardation value d · (na-nb) (=R1) of the phase difference compensator **2402** and **2403** illustrated in Figure **31**, and the line/curve in the figure represents the most suitable value for R1 for various retardation values of the liquid crystal layer.

In Figure **39**, the horizontal axis represents the above-described value R1, the vertical axis R2a represents the retardation value d · (na-nb) of the phase plates **2404** and **2405**, and the line/curve in the figure represents the most suitable value for R2a for various values of R1.

In Figure **40**, the horizontal axis represents the above-described value R2a, the vertical axis -R2b represents the retardation value -d·(na-nc) of the phase plates **2404** and **2405**, and the line/curve in the figure represents the most suitable value for R2b for various values of R2a.

Substantially any liquid crystal display device having the retardation value as shown in Figures **38-40** exhibits good viewing angle characteristics. Thus, the

effective range of retardation value of the present invention is not limited to those described in the examples above, but it is possible to obtain desirable viewing angle characteristics by appropriately setting the retardation value of the liquid crystal layer and that of the phase difference compensator. The effects of the present invention can be sufficiently realized when the retardation value of the liquid crystal layer is in the range of about 240 nm to about 320 nm.

Moreover, the effective conditions of the present invention are not limited to those shown in Figures 38-40. This is because the lines/curves shown in Figures 38 and 39 are obtained by optimizing the retardation values for the liquid crystal cell based on the retardation values of the polarizing plate protecting TACs 2406 and 2407 as shown in Table 47; therefore, the lines/curves shown in Figures 38 and 39 may change when the polarizing plate protecting material and thus the retardation value thereof, or the like, is changed. Moreover, the line/curve shown in Figure 38 only holds for the twist angles and orientations shown in Table 45 and the angles of the na axes of the phase plates 2402 and 2403. Thus, the line/curve of Figure 37 may change as these values change.

Furthermore, the line/curve of Figure **38** holds as long as the liquid crystal cell **2401** produces a black display in the absence of an applied voltage. Using a Poincare' sphere, there are typically a countless number of phase difference compensator settings which provide the above-described effect, for various liquid crystal orientations (the twist angle, the orientation). Even then, by using the phase difference compensator **2402** and **2403**, or other phase difference compensators, it is possible to suppress the degradation of black display in an inclined viewing angle in the absence of an applied voltage, thereby obtaining desirable viewing angle characteristics. It has been particularly illustrated that the black display is suppressed in various examples above. Moreover, it will be briefly discussed in Example 16 below that there are a countless number of combinations and arrangements of a liquid crystal cell, phase difference compensators, and polarizing plates with which the normally black mode characteristics can be obtained.

Examples 15-A to 15-D and Comparative Examples 15-E to 15-H

In Example 15, the three pairs of phase difference

compensators (**2402, 2403**), (**2404, 2405**) and (**2406, 2407**), each pair having the same refractive index anisotropy, are provided to interpose the liquid crystal cell **2401** therebetween. In Examples 15-A to 15-D and Comparative

5   Examples 15-E to 15-H, the effect of providing omitting one phase difference compensator from one or more pairs of phase difference compensators. However, both of the TACs for protecting polarizing plates, i.e., the phase plates **2406** and **2407** are always provided on the respective

10   sides of the liquid crystal cell in any of the examples.

Table 48   below   shows   the   arrangement (presence/absence) of the respective phase difference compensators for each of the examples.

TABLE 48

Example #	2402	2403	2404	2405	2406	2407	Viewing angle characteristics
Example 15	Yes	Yes	Yes	Yes	Yes	Yes	◎
Example 15-A	Yes	Yes	Yes	No	Yes	Yes	○
Example 15-B	Yes	Yes	No	Yes	Yes	Yes	○
Example 15-C	No	Yes	Yes	Yes	Yes	Yes	○
Example 15-D	Yes	No	Yes	Yes	Yes	Yes	○
Comparative example 15-E	No	Yes	Yes	No	Yes	Yes	✕
Comparative example 15-F	No	Yes	No	Yes	Yes	Yes	✕
Comparative example 15-G	Yes	No	Yes	No	Yes	Yes	✕
Comparative example 15-H	Yes	No	No	Yes	Yes	Yes	✕

Example 15-A

A structure of a liquid crystal display device according to Example 15-A will be described below. The basic structure of the liquid crystal display device is as illustrated in Figure 31, except that the phase difference compensator 2405 is omitted as shown in Table 48.

First, the parameters for the liquid crystal cell

are shown in Table 49 below.

TABLE 49

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	260nm	0deg	90deg
B	50%	260nm	0deg	270deg

Next, the parameters for the polarizers are shown

in Table 50 below.

TABLE 50

Ref # of polarizing plate	Angle of transmission axis
2408	45deg
2409	−45deg

Finally, the parameters for the phase difference

compensators are shown in Table 51 below.

TABLE 51

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
2402	130nm	0nm	0deg
2403	130nm	0nm	0deg
2404	184nm	−184nm	−45deg
2405	——————Not provided————————		
2406	5nm	50nm	−45deg
2407	5nm	50nm	45deg

Figure 41 illustrates an isocontrast contour

curve based on values obtained by dividing the transmissivity for an applied voltage of 4 V by the transmissivity for an applied voltage of 0 V in the liquid crystal display device of Example 15-A.

5

Example 15-B

The structure of a liquid crystal display device according to Example 15-B will be described below. The basic structure of the liquid crystal display device is

10 as illustrated in Figure 31, except that the phase difference compensator 2404 is omitted as shown in Table 48.

First, the parameters for the liquid crystal cell

15 are shown in Table 52 below.

TABLE 52

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	260nm	0deg	90deg
B	50%	260nm	0deg	270deg

Next, the parameters for the polarizers are shown in Table 53 below.

TABLE 53

Ref # of polarizing plate	Angle of transmission axis
2408	45deg
2409	−45deg

Finally, the parameters for the phase difference

compensators are shown in Table 54 below.

TABLE 54

Ref # of phase plate	d*(na-nb)	d*(na-nc)	Angle of na axis
2402	130nm	0nm	0deg
2403	130nm	0nm	0deg
2404	— — — — — —Not provided— — — — — — —		
2405	184nm	−184nm	45deg
2406	5nm	50nm	−45deg
2407	5nm	50nm	45deg

Figure 42 illustrates an isocontrast contour curve based on values obtained by dividing the transmissivity for an applied voltage of 4 V by the transmissivity for an applied voltage of 0 V in the liquid crystal display device of Example 15-B.

Example 15-C

The structure of a liquid crystal display device according to Example 15-C will be described below. The basic structure of the liquid crystal display device is as illustrated in Figure 31, except that the phase

difference compensator **2402** is omitted as shown in Table 48.

First, the parameters for the liquid crystal cell

5   are shown in Table 55 below.

TABLE 55

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	260nm	0deg	90deg
B	50%	260nm	0deg	270deg

Next, the parameters for the polarizers are shown

in Table 56 below.

TABLE 56

Ref # of polarizing plate	Angle of transmission axis
2408	45deg
2409	−45deg

Finally, the parameters for the phase difference

compensators are shown in Table 57 below.

TABLE 57

Ref # of phase plate	d*(na-nb)	d*(na-nc)	Angle of na axis
2402	——————Not provided————————		
2403	260nm	0nm	0deg
2404	92nm	−92nm	−45deg
2405	92nm	−92nm	45deg
2406	5nm	50nm	−45deg
2407	5nm	50nm	45deg

Figure **43** illustrates an isocontrast contour curve based on values obtained by dividing the transmissivity for an applied voltage of 4 V by the transmissivity for an applied voltage of 0 V in the liquid crystal display device of Example 15-C.

Example 15-D

The structure of a liquid crystal display device according to Example 15-D will be described below. The basic structure of the liquid crystal display device is as illustrated in Figure **31**, except that the phase difference compensator **2403** is omitted as shown in Table 48.

First, the parameters for the liquid crystal cell are shown in Table 58 below.

TABLE 58

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	260nm	0deg	90deg
B	50%	260nm	0deg	270deg

5   Next, the parameters for the polarizers are shown

in Table 59 below.

TABLE 59

Ref # of polarizing plate	Angle of transmission axis
2408	45deg
2409	−45deg

        Finally, the parameters for the phase difference

compensators are shown in Table 60 below.

TABLE 60

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
2402	260nm	0nm	0deg
2403	——————Not provided———————		
2404	92nm	−92nm	−45deg
2405	92nm	−92nm	45deg
2406	5nm	50nm	−45deg
2407	5nm	50nm	45deg

        Figure **44** illustrates an isocontrast contour

curve based on values obtained by dividing the

transmissivity for an applied voltage of 4 V by the

transmissivity for an applied voltage of 0 V in the liquid crystal display device of Example 15-D.

Example 15-E

5   The structure of a liquid crystal display device according to Example 15-E will be described below. The basic structure of the liquid crystal display device is as illustrated in Figure **31**, except that the phase difference compensators **2402** and **2405** are omitted as shown

10   in Table **48**.

          First, the parameters for the liquid crystal cell are shown in Table 61 below.

TABLE 61

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	260nm	0deg	90deg
B	50%	260nm	0deg	270deg

          Next, the parameters for the polarizers are shown

20   in Table 62 below.

TABLE 62

Ref # of polarizing plate	Angle of transmission axis
2408	45deg
2409	−45deg

Finally, the parameters for the phase difference compensators are shown in Table 63 below.

TABLE 63

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
2402	——————Not provided————————		
2403	260nm	0nm	0deg
2404	184nm	−184nm	−45deg
2405	——————Not provided————————		
2406	5nm	50nm	−45deg
2407	5nm	50nm	45deg

Figure **45** illustrates an isocontrast contour curve based on values obtained by dividing the transmissivity for an applied voltage of 4 V by the transmissivity for an applied voltage of 0 V in the liquid crystal display device of Example 15-E.

Comparative Example 15-F

The structure of a liquid crystal display device according to Comparative Example 15-F will be described below. The basic structure of the liquid crystal display

device is as illustrated in Figure 31, except that the phase difference compensators **2402** and **2404** are omitted as shown in Table 48.

5   First, the parameters for the liquid crystal cell are shown in Table 64 below.

TABLE 64

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	260nm	0deg	90deg
B	50%	260nm	0deg	270deg

Next, the parameters for the polarizers are shown in Table 65 below.

TABLE 65

Ref # of polarizing plate	Angle of transmission axis
2408	45deg
2409	−45deg

Finally, the parameters for the phase difference
20   compensators are shown in Table 66 below.

TABLE 66

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
2402	------Not provided-------		
2403	260nm	0nm	0deg
2404	------Not provided-------		
2405	184nm	−184nm	45deg
2406	5nm	50nm	−45deg
2407	5nm	50nm	45deg

Figure **46** illustrates an isocontrast contour curve based on values obtained by dividing the transmissivity for an applied voltage of 4 V by the transmissivity for an applied voltage of 0 V in the liquid crystal display device of Comparative Example 15-F.

Comparative Example 15-G

The structure of a liquid crystal display device according to Comparative Example 15-G will be described below. The basic structure of the liquid crystal display device is as illustrated in Figure **31**, except that the phase difference compensators **2403** and **2405** are omitted as shown in Table 48.

First, the parameters for the liquid crystal cell are shown in Table 67 below.

TABLE 67

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	260nm	0deg	90deg
B	50%	260nm	0deg	270deg

5   Next, the parameters for the polarizers are shown

in Table 68 below.

TABLE 68

Ref # of polarizing plate	Angle of transmission axis
2408	45deg
2409	−45deg

Finally, the parameters for the phase difference

compensators are shown in Table 69 below.

TABLE 69

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
2402	260nm	0nm	0deg
2403	——————— Not provided —————————		
2404	184nm	−184nm	−45deg
2405	——————— Not provided —————————		
2406	5nm	50nm	−45deg
2407	5nm	50nm	45deg

Figure **47** illustrates an isocontrast contour

curve based on values obtained by dividing the

transmissivity for an applied voltage of 4 V by the

transmissivity for an applied voltage of 0 V in the liquid crystal display device of Comparative Example 15-G.

Comparative Example 15-H

The structure of a liquid crystal display device according to Comparative Example 15-H will be described below. The basic structure of the liquid crystal display device is as illustrated in Figure **31**, except that the phase difference compensators **2403** and **2404** are omitted as shown in Table 48.

First, the parameters for the liquid crystal cell are shown in Table 70 below.

TABLE 70

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	260nm	0deg	90deg
B	50%	260nm	0deg	270deg

Next, the parameters for the polarizers are shown in Table 71 below.

TABLE 71

Ref # of polarizing plate	Angle of transmission axis
2408	45deg
2409	−45deg

Finally, the parameters for the phase difference compensators are shown in Table 72 below.

TABLE 72

Ref # of phase plate	d*(na−nb)	d*(na−nc)	Angle of na axis
2402	260nm	0nm	0deg
2403	—————Not provided————————		
2404	—————Not provided————————		
2405	184nm	−184nm	45deg
2406	5nm	50nm	−45deg
2407	5nm	50nm	45deg

Figure **48** illustrates an isocontrast contour curve based on values obtained by dividing the transmissivity for an applied voltage of 4 V by the transmissivity for an applied voltage of 0 V in the liquid crystal display device of Comparative Example 15-H.

In Comparative Examples 15-E to 15-H where one of the phase difference compensators **2402** and **2403** is omitted while also omitting one of the phase difference compensators **2404** and **2405** from the structure of Exam-

ple 15, the contrast is about 20 or less for a viewing angle of about 50° or greater in any azimuth angle including the X_REF±45° directions, the X_REF direction and the Y_REF direction, indicating deterioration of the

5   viewing angle characteristics, as shown in the respective isocontrast contour curves (Figures **45** to **48**).

In Examples 15-C and 15-D where only one of the phase difference compensators **2402** and **2403** is omitted

10   from the structure of Example 15, the isocontrast contour curve (see Figures **43** and **44**) indicates better characteristics in the X_REF and Y_REF directions than those indicated by any of the isocontrast contour curves of Comparative Examples 15-E to 15-H.

15

In Examples 15-A and 15-B where only one of the phase difference compensators **2404** and **2405** is omitted from the structure of Example 15, the isocontrast contour curve (see Figures **41** and **42**) indicates better

20   characteristics in the X_REF±45° directions than those indicated by any of the isocontrast contour curves of Comparative Examples 15-E to 15-H.

Thus, desirable viewing angle characteristics can

be obtained by providing both of at least one of the pairs
of phase difference compensators (2402, 2403) and (2404,
2405) on the respective sides of the liquid crystal cell.

Preferably, the same number of phase difference
compensators are symmetrically provided respectively on
the light source side and on the viewer side of the liquid
crystal cell, as in Example 15. In such a case, even
better viewing angle characteristics can be obtained.
More preferably, a pair of phase difference compensators
provided respectively on the light source side and on the
viewer side at the same distance from the intermediate
layer of the liquid crystal cell have the same retardation
value. In Example 15, a pair of phase difference
compensators 2402 and 2403 have the same retardation value,
while another pair of phase difference compensators 2404
and 2405 have the same retardation value. In Exam-
ples 15-A to 15-D, one of the phase difference
compensators 2402, 2403, 2404 and 2405 is omitted or has
a retardation value of zero. Thus, it can be expected that
desirable viewing angle characteristics can be obtained
also when none of the phase difference compensators 2402,
2403, 2404 and 2405 is omitted, but a pair of the phase
difference compensators have different retardation

values.

A common requirement for Examples 11 and 15 is that
the transmission axis of the light source side polarizer
(6206, 2408) is perpendicular to the transmission axis
of the viewer side polarizer (6207, 2409).   Another
requirement common to these examples is that the na axis
of any one of the phase difference compensators 6204, 6205,
2404 and 2405 is substantially perpendicular to the
transmission axis of the immediately adjacent one of the
phase difference compensators.   There is no limitation to
the angle of the light source side polarizer, but the angle
may be about -45°, or any other angle, other than about
45° as in the illustrated examples.   It should be noted,
however, that when the angle is about 0° or about 90°,
a sufficient transmissivity may not be obtained in the
presence of an applied voltage (when producing a white
display).   As long as the common requirements are
satisfied, the effects of the present invention can be
obtained with a liquid crystal cell having a twist angle
of about 0°.   In Examples 11 and 13, the na axes of the
phase difference compensators 6202 and 6203 (6402 and
6403) are parallel to each other and perpendicular to the
rubbing axis of the liquid crystal cell 6201 (6401), in

order to obtain even more desirable effects.

Example 16

In Example 11 above, the na axis of a phase plate adjacent to the liquid crystal cell having no twist is varied so as to obtain a desirable black display in the direction normal to the liquid crystal display device, with a liquid crystal cell having a twist angle of about 30°. In particular, the na axes of the phase difference compensators on the respective sides of the liquid crystal cell are parallel to each other at a twist angle of zero, while the na axes are at an appropriate setting angle (about 18.8° in Example 11) at a twist angle of about 30°. In Example 16, it will be confirmed that a desirable black display in the normal direction as in Example 11 can be obtained for a liquid crystal cell having a twist angle other than about 0°, by methods other than the above. It will also be discussed briefly that there exist a countless number of combinations of phase difference compensators with which a black display can be produced in the normal direction in the absence of an applied voltage by using Poincare' sphere.

A liquid crystal cell of Example 16 is

structurally similar to that illustrated in Figure 31,
but the parameters for the polarizers, the liquid crystal
cell and the phase difference compensators are different.
The parameters for the liquid crystal cell **2401** of

5   Example 16 are as follows.

TABLE 73

Region	Area in percent for the entire pixel	Retardation value	Twist angle	Orientation
A	50%	260nm	−30deg	90deg
B	50%	260nm	−30deg	270deg

Next, the parameters for the polarizers of
Example 16 are shown in Table 74 below.

TABLE 74

Ref # of polarizing plate	Angle of transmission axis
2408	28deg
2409	−28deg

Finally, the parameters for the phase difference
compensators of Example 16 are shown in Table 75 below.

TABLE 75

Ref # of phase plate	d*(na-nb)	d*(na-nc)	Angle of na axis
2402	75nm	0nm	0deg
2403	75nm	0nm	0deg
2404	92nm	−92nm	−45deg
2405	92nm	−92nm	45deg
2406	5nm	50nm	−62deg
2407	5nm	50nm	62deg

Figure **49** illustrates the relationship between the transmissivity in the normal direction and the applied voltage in the liquid crystal display device of the present example.   As illustrated in Figure **49,** the liquid crystal display device of the present example has a transmissivity of substantially 0% when the applied voltage is about 0 V. The liquid crystal display device has normally black electro-optical characteristics where the transmissivity increases as the applied voltage increases to be about 1.5 V or more. It is also shown that desirable contrast characteristics are obtained because the transmissivity is about 0% when the applied voltage is about 0 V.

Figure **50** illustrates an isocontrast curve for the liquid crystal display device of the present example. The isocontrast contour curve of Figure **50** is based on values (contrast ratios) obtained by dividing the transmissivity for an applied voltage of 4 V by the

transmissivity for an applied voltage of 0 V. It can be seen from Figure 50 that the liquid crystal display device of the present example has desirable electro-optical characteristics as in other examples such as Examples 15 and 11.

Next, it will be discussed that there are a countless number of setting combinations respectively for the liquid crystal cell, for the polarizing plates, and for the phase difference compensators, with which a black display is obtained in the normal direction.

First, how a black display is obtained in the normal direction in Example 16 will be generally discussed, with reference to Poincare' sphere shown in Figure 51, wherein:

Point A represents the polarization of light having passed through the polarizing plate 2408 and the phase difference compensator 2406;

Point B represents the polarization of light having passed through the phase difference compensator 2404;

Point C represents the polarization of light having passed through the phase difference compensa-

tor **2402**;

Point D represents the polarization of light having passed through the liquid crystal cell **2401**;

Point E represents the polarization of light

5   having passed through the phase difference compensator **2403**;

Point F represents the polarization of light having passed through the phase difference compensators **2405** and **2407**;

10   Point G represents the polarization of light which is transmitted by the polarizer **2409**;

Axis l represents a rotary axis on the Poincare' sphere which corresponds to the birefringence effect provided by the phase difference compensator **2406**;

15   Axis m represents a rotary axis on the Poincare' sphere which corresponds to the birefringence effect provided by the phase difference compensators **2404** and **2405**;

Axis n represents a rotary axis on the Poincare'

20   sphere which corresponds to the birefringence effect provided by the phase difference compensator **2402**;

Axis o1 represents a rotary axis on the Poincare' sphere which corresponds to the birefringence effect provided by liquid crystal molecules in the liquid crystal

cell which are adjacent to the phase difference compensator **2402**;

Axis o2 represents a rotary axis on the Poincare' sphere which corresponds to the birefringence effect provided by liquid crystal molecules in the liquid crystal cell which are adjacent to the phase difference compensator **2403**; and

Axis p represents a rotary axis on the Poincare' sphere which corresponds to the birefringence effect, provided by the phase difference compensator **2407**.

Figure **51** illustrates a Poincare' sphere as viewed from a pole thereof. Therefore, the center point S in Figure **51** represents circularly-polarized light, a point along the periphery (equator) represents linearly-polarized light, and a point between the center point S and the periphery represents elliptically-polarized light. Each of the numerals shown around the periphery is the angle between the polarization axis of the corresponding linearly-polarized light and the X_REF axis.

Referring to Figure **51**, the transition of polarization of light having a wavelength of about 550 nm

traveling from the light source to the viewer will be described.

The linearly-polarized light passing through the polarizing plate **2408** illustrated in Figure **31** is at point A. Since the na axis of the phase difference compensator **2406** is perpendicular to the transmission axis of the polarizing plate **2408**, the linearly-polarized light at Point A is rotated about Axis 1 by the phase difference compensator **2406**. As a result, the light at Point A is not moved from Point A.

Since the angle of the na axis of the phase difference compensator **2404** is about -45°, the light at Point A along the equator is rotated about Axis m. Since the value of d·(na-nb) of the phase difference compensator **2404** is about 92 nm, the rotation angle is about 60°. As a result, the light at Point A along the equator is moved to Point B.

Since the na axis of the phase difference compensator **2402** is about 0°, the light at Point B is rotated about Axis n. Since the value of d·(na-nb) of the phase difference compensator **2402** is about 75 nm, the

rotation angle is about 49°. As a result, the light at Point B is moved to Point C.

Since the main axis of the refractive index anisotropy of the liquid crystal cell **2401** continuously rotates from about 105° to about 75°, from the light source side to the viewer side, the light at Point C is rotated about an axis which continuously moves from Axis o1 to Axis o2. Since the retardation value of the liquid crystal cell **2401** is about 260 nm, the rotation angle about the axis is about 170°. As a result, the light at Point C is moved generally along a path as illustrated in Figure **51** to Point D which is located on the other (hidden) hemisphere via the equator.

Since the na axis of the phase difference compensator **2403** is about 0°, the light at Point D is rotated about Axis n. Since the retardation value d· (na-nb) of the phase difference compensator **2403** is about 75 nm, the rotation angle is about 49°. As a result, the light at Point D is moved to Point E.

Since the na axis of the phase difference compensator **2405** is about 45°, the light at Point E is

rotated about Axis m. Since the value d·(na-nb) of the phase difference compensator **2405** is about 92 nm, the rotation angle is about 60°. As a result, the light at Point E is moved to Point F which is generally along the equator.

Since the na axis of the phase difference compensator **2407** is perpendicular to the transmission axis of the polarizer **2409**, the light at Point F is rotated about Axis p. As a result, the light at Point F is not moved from Point F.

Then, since the transmission axis of the polarizer **2409** at Point G is on the opposite end of Axis p with respect to Point F, the polarized light having passed through the phase difference compensator **2407** is blocked by the polarizer **2409**. As a result, the liquid crystal display device of the present example exhibits normally black electro-optical characteristics in which the transmissivity is about 0% for an applied voltage of about 0 V.

Example 11 (another example where the twist angle of the liquid crystal cell is about 30°) can also be

examined as in Example 16. Figure **52** illustrates a path of transition of polarized light in Example 11, wherein:

Point A represents the polarization of light having passed through the polarizer **6206** and the phase difference compensator **6204**;

Point B represents the polarization of light having passed through the phase difference compensator **6202**;

Point C represents the polarization of light having passed through the liquid crystal cell **6201**;

Point D represents the polarization of light having passed through the phase difference compensators **6203** and **6205**; and

Point E represents the polarization of light which is transmitted by the polarizer **6207**.

The transition will be briefly described below. The linearly-polarized light having passed through the polarizer **6206** illustrated in Figure **24** is located at Point A. The phase difference compensator **6204** does not move the light at Point A. Then, the light is moved to Point B by the phase difference compensator **6202**, to Point C by the liquid crystal cell **6201**, and to Point D by the phase difference compensator **6203**. The light at

Point D is not moved by the phase difference compensator 6205. Point D is substantially identical to Point A, which is on the opposite end of an axis of the sphere with respect to Point E representing the polarization of
5   linearly-polarized light which is transmitted by the polarizer 6207 on the viewer side. Therefore, the polarized light having passed through the phase difference compensator 6205 is blocked by the polarizer 6207. Thus, the liquid crystal display device of Example 11 also
10   exhibits normally black mode electro-optical characteristics in which the transmissivity is about 0% for an applied voltage of about 0 V.

Finally, a case where the liquid crystal cell has
15   a twist angle of about 0°, e.g., Example 15, will be examined as in Example 16. Figures 53A and 53B illustrate a path of transition of polarized light in Example 15, wherein:

Point A represents the polarization of light
20   having passed through the polarizer 2408 and the phase difference compensators 2406 and 2404;

Point B represents the polarization of light having passed through the phase difference compensator 2402;

Point C represents the polarization of light having passed through the liquid crystal cell **2401**;

Point D represents the polarization of light having passed through the phase difference compensa-

5   tors **2403**, **2405** and **2407**; and

Point E represents the polarization of light which is transmitted by the polarizer **2409**.

The transition will be briefly described below.

10 The linearly-polarized light having passed through the polarizer **2408** illustrated in Figure **31** is located at Point A. The phase difference compensators **2406** and **2404** do not move the light at Point A. Then, the light is moved to Point B by the phase difference compensator **2402**, to

15 Point C which is located on the other (hidden) hemisphere by the liquid crystal cell **2401**, and to Point D along the equator by the phase difference compensator **2403**. The light at Point D is not moved by the phase difference compensators **2405** and **2407**. Point D is substantially

20 identical to Point A, which is on the opposite end of an axis of the sphere with respect to Point E representing the polarization of linearly-polarized light which is transmitted by the polarizer **2409** on the viewer side. Therefore, the polarized light having passed through the

phase difference compensator **2407** is blocked by the polarizer **2409**. Thus, the liquid crystal display device of Example 15 also exhibits normally black mode elec-tro-optical characteristics in which the transmissivity

5   is about 0% for an applied voltage of about 0 V.

As described above with respect to the illustrative examples of the present invention, normally black mode characteristics which produce a black display

10   in the absence of an applied voltage can be obtained by appropriately setting the parameters of the liquid crystal cell and the phase difference compensators so that the polarization direction of light having passed through the polarizing plate on the light source side is at a right

15   angle with the polarization direction of light which is transmitted by the polarizing plate on the viewer side, i.e., along the polarization direction of light which is absorbed by a polarizing plate on the viewer side. A countless number of such settings can be found by using

20   a Poincare' sphere. This is because, referring to Fig-ure **54**, there exist a countless number of possible paths extending from Point A (representing the polarization of light having passed through the polarizing plate on the light source side) to Point Z (representing the

polarization of light which is absorbed by the polarizing plate on the viewer side.

However, as can be seen from the comparative examples above, it is preferred in view of obtaining desirable viewing angle characteristics to symmetrically provide the same number of phase difference compensators on the light source side and the viewer side of the liquid crystal cell.

As described above, the liquid crystal display device of the present invention performs a display in a normally black mode (where a black display is produced in the absence of an applied voltage) by applying a substantially vertical electric field across a liquid crystal layer made of a nematic liquid crystal material having a positive dielectric anisotropy which is provided between a pair of polarizing plates in a crossed Nicols arrangement. The liquid crystal layer in each pixel region includes at least a first domain and a second domain where the liquid crystal molecules have different orientations, whereby it is possible to suppress the change in display quality due to the change in viewing angle.

In any viewing angle including the normal direction, the phase difference compensator compensates for the refractive index anisotropy of liquid crystal
5   molecules which are in a substantially horizontal orientation with respect to the substrate surface in the absence of an applied voltage, thereby realizing a black display with a reduced viewing angle dependency. Moreover, when using, as phase difference compensators,
10   a pair of phase plates each having a positive refractive index anisotropy which are arranged on the respective sides of the liquid crystal layer so that the phase-delay axes thereof are parallel to the substrate surface and perpendicular to the phase-delay axis of the liquid
15   crystal layer, it is possible to effectively compensate for the refractive index anisotropy of the liquid crystal molecules as viewed from the normal direction.

Furthermore, by arranging the phase plate having
20   a positive refractive index anisotropy so that the phase-delay axis thereof is substantially perpendicular to the substrate surface, it is possible to compensate for the change in retardation of the liquid crystal layer whose phase-delay axis lies in a plane parallel to the

substrate surface and that of the phase difference compensator, which result as the viewing direction (viewing angle) is inclined.

5   Moreover, by arranging the phase plate having a positive refractive index anisotropy so that the phase-delay axis thereof is perpendicular to the polarization axis of the polarizing plate (i.e., at about 45° with respect to the phase-delay axis of the liquid
10   crystal layer), it is possible to compensate for the rotation of elliptically-polarized light. As a result, a desirable black display can be obtained in any viewing angle including the normal direction.

15   The present invention provides a liquid crystal display device in a normally black mode in which the change in display quality due to a change in viewing angle is significantly reduced. The liquid crystal display device of the present invention does not sacrifice any of the
20   production efficiency and the transmissivity as in a conventional wide viewing angle liquid crystal display device. The liquid crystal display device of the present invention can be suitably used in various display device applications where a wide viewing angle is required, such

as a liquid crystal display device as a computer monitor
and a liquid crystal display device for displaying video
images.

5   Various other modifications will be apparent to
and can be readily made by those skilled in the art without
departing from the scope and spirit of this invention.
Accordingly, it is not intended that the scope of the
claims appended hereto be limited to the description as
10   set forth herein, but rather that the claims be broadly
construed.